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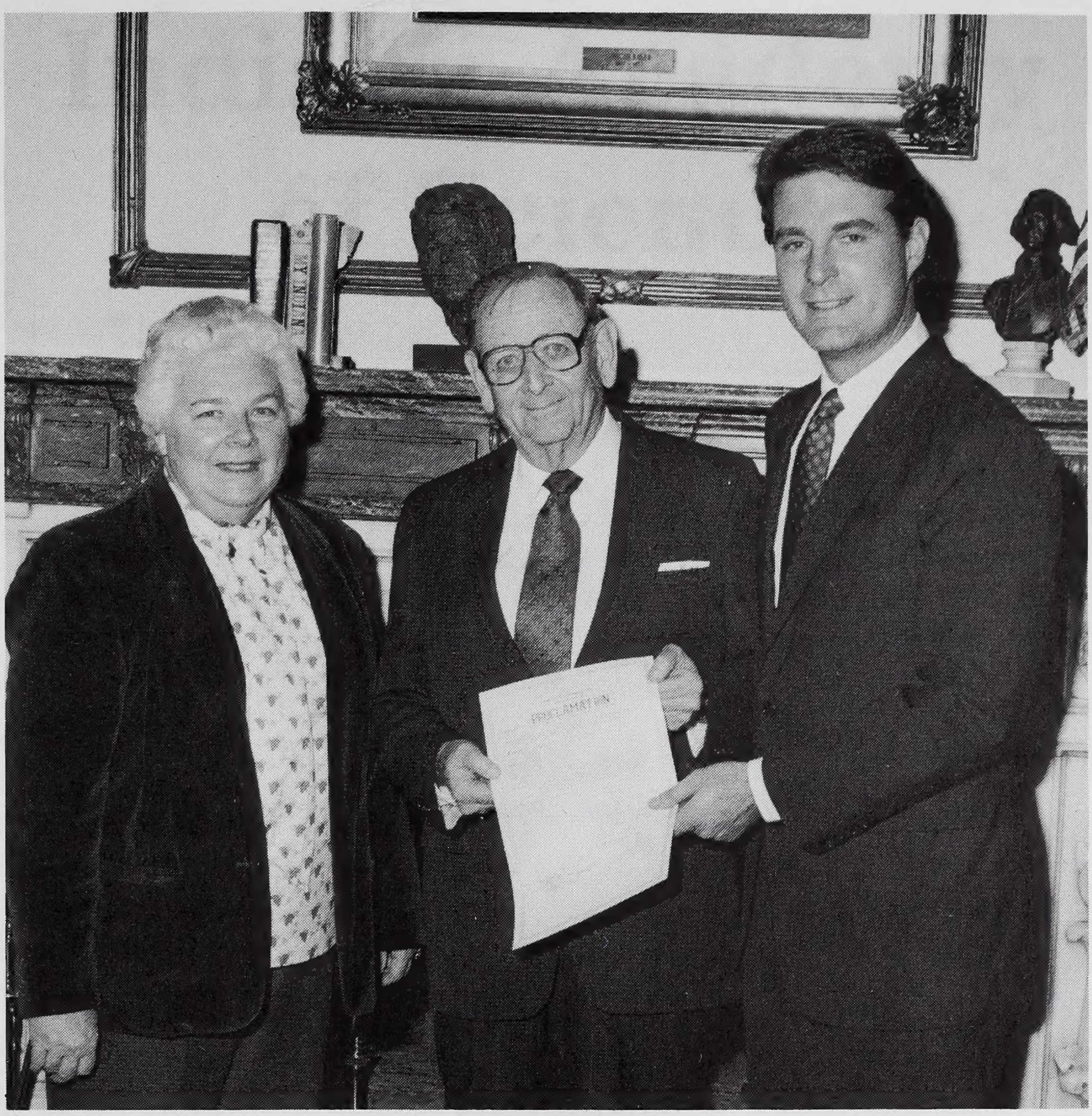

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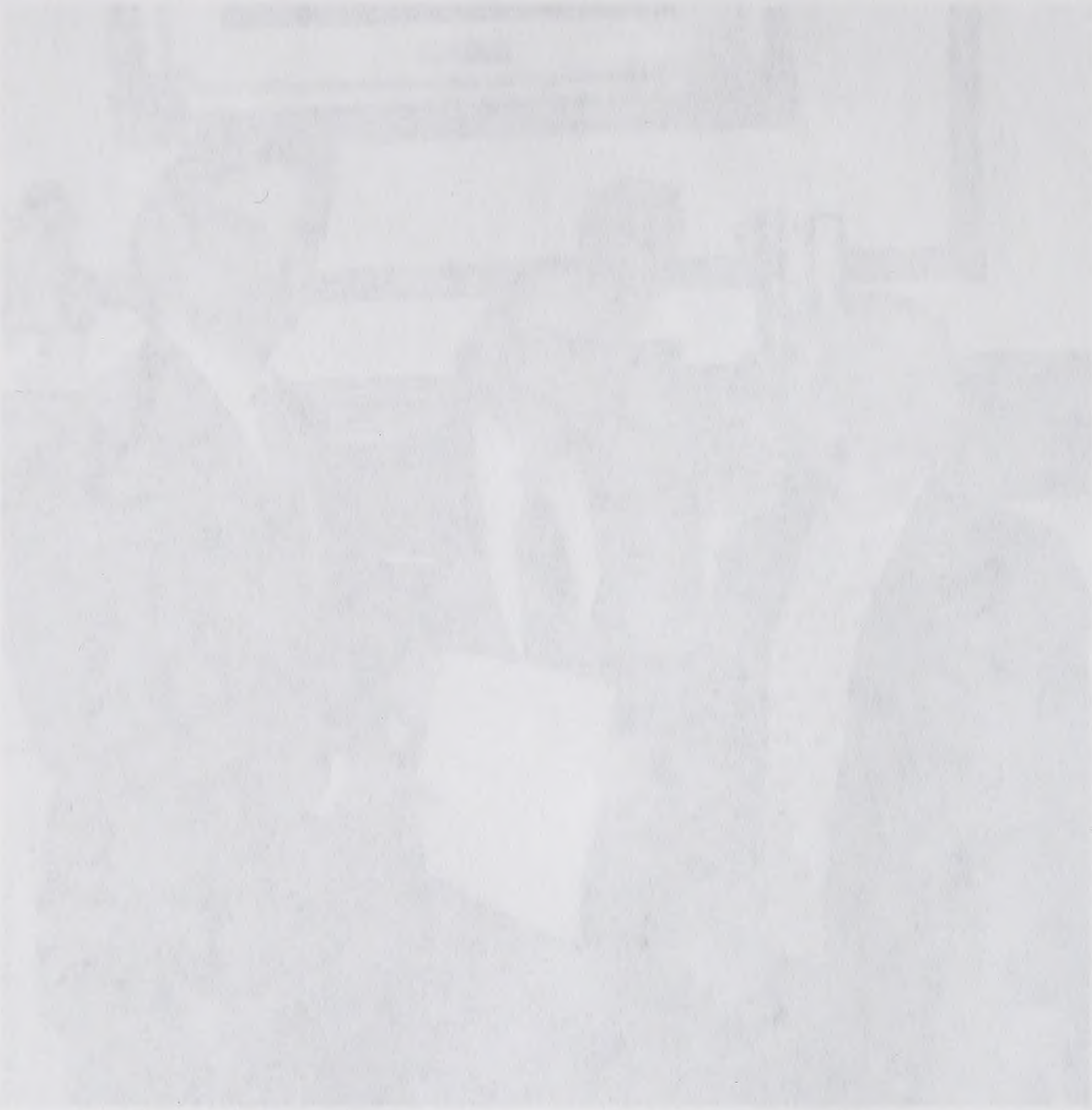
The Indiana Academy of Science wishes to express its sincere appreciation to Dr. Donald R. Winslow for his dedicated service as the Editor of the *Proceedings* and Executive Officer of the Academy. Dr. Winslow is shown here accepting a certificate proclaiming Indiana Academy of Science Recognition Week from Gov. Bayh. Also present was Dr. Charlotte M. Boener, IAS President in 1989.



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GARY E. DOLPH, Editor
Kokomo, Indiana

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Notre Dame, Indiana

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Proceedings
# of the
Indiana Academy
# of Science

Part I
The Work of
the Academy

INDIANA ACADEMY OF SCIENCE OFFICERS AND EXECUTIVE COMMITTEE, 1988

President . . . . WILTON N. MELHORN, Department of E.A.S.
Purdue University, West Lafayette, IN 47907
(317) 494-3277, SUVON—+755-43277

President-Elect . . . . CHARLOTTE BOENER, Science Teaching Center
Indiana State University, Terre Haute, IN 47809
(812) 237-6311, ext. 3010, SUVON—+749-3010

Secretary . . . . RICHARD L. CONKLIN, Department of Physics
(1986-88) Hanover College, Hanover IN 47243
(812) 866-2151, ext. 348, SUVON—+719-348

Treasurer . . . . DUVALL A. JONES, Department of Biology
(1988-90) St. Joseph's College, Rensselaer, IN 47978
(219) 866-7111, ext. 214, SUVON—+741-214

Director of Public Relations . . . ALFRED R. SCHMIDT, Department of Mathematics
(1988-90) Rose-Hulman Institute of Tech., Terre Haute, IN 47803
(812) 877-1511, SUVON—+739-288

Editor of *Proceedings* . . . . DONALD R. WINSLOW, School of Education
(1988-90) Indiana University, Bloomington, IN 47405
(812) 335-8658, SUVON—+703-58658

Immediate Past President . . . . . . STANLEY L. BURDEN, Nussbaum Science Center
Taylor University, Upland, IN 46989
(317) 988-5272, SUVON—+748-5272

THE COUNCIL

The Council is the principal governing body of the Academy. The Council consists of the Past Presidents, the current Officers, the Chairs of all sections and committees, the Directors of the programs of the Youth Activities Committee, and representatives of affiliated organizations. For current Council membership, see parts of this Directory listing these offices and appointments.

Budget Committee

WILTON N. MELHORN, President
CHARLOTTE BOENER, President-Elect
RICHARD L. CONKLIN, Secretary
DUVAL A. JONES, Treasurer
ALFRED R. SCHMIDT, Director of Public Relations
DONALD R. WINSLOW, Editor
STANLEY L. BURDEN, Immediate Past President
DAVID SEVER, Co-Chair, Program Committee
RICHARD J. JENSEN, Co-Chair, Program Committee
EDWIN SQUIERS, Science and Society Committee
HOLLY OSTER, Library Committee
VIRGINIA RHODES, Youth Activities Committee

Frank Guthrie, Academy Foundation
Austin Brooks, Research Grants Committee
Mark Whitman, Director, Junior Academy of Science Council
Jan Woerner, Director, Science Olympiad
Benjamin Moulton, Chair, Publications Committee

COMMITTEE CHAIRPERSONS AND SPECIAL APPOINTMENTS

I. Elected Committees

1. Academy Foundation	Frank Guthrie, Chair (1990) Ernest Campaigne (1989) Max Marsh (1988) Duval Jones (ex-off.)
2. Bonding	Mary Lee Richeson, Chair (1988) John Whitaker (1989)
3. Research Grants	Austin Brooks, Chair (1989)-Biology Joan E. Lafuze (1992) Wilson B. Lutz (1990)-Chemistry James E. Newman (1988)-Agriculture Benjamin Swartz (1989)-Anthropology Richard Conklin (ex-off.)

II. Standing and Ad Hoc Committees, and Special Appointments

4. Academy Representative to AAAS	Virginia Rhodes (1988)
5. Academy Representative, Indiana Natural Resources Commission	Rev. Damian Schmelz
6. Amendments	William Eberly, chair (Parliamentarian) E. E. Campaigne Don Winslow
7. Archivist	Holly Oster
8. Auditing Committee	John Ricketts, Chair David D. Chesak
9. Biological Survey Committee	John A. Bacone, Chair John S. Castrale James R. Gammon J. D. Haddock Richard Jensen Daryl R. Karns Clifton A. Keller William M. McKnight Jack R. Munsee Victor Riemenschneider

	John R. Schrock John O. Whitaker
10. Editorial Board, *Proceedings* (term for all members coincides with term of Chair)	Donald R. Winslow, Chair (1988-90) Hans O. Andersen Rita Barr Ernest E. Campaigne William R. Clark Robert F. Dale James R. Gammon James H. Kellar Benjamin Moulton Van E. Neie John F. Pelton Alfred Schmidt J. Dan Webster Terry R. West John O. Whitaker, Jr.
11. Emeritus Member Selection Committee	Robert H. Cooper, Chair Harry G. Day Howard H. Michaud Winona H. Welch
12. Fellows Committee	William R. Gommel (1990), Chair Marvin Carmack (1988) Jack Albright (1989) John Bacone (1990) Jacques W. Delleur (1988) Frank K. Edmondson (1988) Donald P. Franzmeier (1990) Uwe Hansen (1989) James Kellar (1989) Jack Munsee (1989) Mary Lee Richeson (1989) Michael J. Sinsko (1989) Charles E. Wier (1988) Harold Zimmack (1989)
13. High School Teacher Research Fellows	Dennis G. Peters, Chair Austin Brooks Susan Speece John Whitaker
14. Indiana Science Talent Search	Donald Winslow, Chair Austin Brooks Russell Coverdale Jo Ann Jansing Alfred Schmidt Harold Zimmack

15. Invitations Committee	Marshall P. Cady, Chair George R. Parker John Ricketts
16. Junior Academy Council	Mark Whitman, Director W. Thomas Anderson, Jr. Michael Kobe Virginia Rhodes
17. Library Committee	Holly Oster, Chair Lois Burton James A. Clark William A. Daily
18. Membership Committee	Charlotte M. Boener, Chair Paul E. Baronowski James Berry Stephen M. Chmiel Duval A. Jones (ex-off.) Barbara Kane Edward Lavagnino James E. Newmann Victor Riemenschneider Gerald Seeley Frank L. Stanonis Eugene D. Weinberg
19. Necrologist	Fay K. Daily
20. *Newsletter* Editor	Alfred E. Schmidt
21. Nominations	Benjamin Moulton, Chair Ernest E. Campaigne Stanley J. Burden
22. Parliamentarian	William R. Eberly
23. Preservation of Natural Areas	Marion T. Jackson, Chair (1990) John A. Bacone (1988) John H. Cleveland (1990) Burnell C. Fischer (1990) Carrolle Markle (Honorary) John Mutz (1988) George Parker (1989) Victor Riemenschneider (1989) Robert C. Weber (1988) William Weeks (1989) Winona Welch (Honorary) Larry R. Yoder (1990)
24. Program Committee	David Sever, Co-Chair Richard Jensen, Co-Chair
25. Public Relations Committee	Alfred R. Schmidt, Co-Chair Duvall Jones, Co-Chair Jean Beckman Charlotte Boener Uwe Hansen

Zoology

JOHN S. CASTRALE
Forest Wildlife Office
R.R. 2, Box 477
Mitchell, IN 47446
(812) 849-4586

TIMOTHY J. BURKHOLDER
Department of Biology
Taylor University
Upland, IN 46989
(317) 998-5334
SUVON___+748-5334

INDIANA ACADEMY OF SCIENCE MEETING OF THE EXECUTIVE COMMITTEE

February 6, 1988

MINUTES

The meeting was called to order by President Wilton Melhorn at 10:05 a.m. in the conference room of the Indiana State Library. Those present were Melhorn, Charlotte Boener, Stanley Burden, Ernest Campaigne, Richard Conklin, Duval Jones, Holly Oster, Alfred Schmidt, and Donald Winslow.

Minutes of the December 12, 1987, Executive Committee meeting were approved.

Melhorn made several announcements:

> The Treasurer has agreed to a settlement of $40 in payment of $387 owed the Academy by the now-bankrupt Purdue-Calumet Bookstore.
> The Directory will be mailed soon. 200 copies will be printed.
> Professional Geologists want to make an annual cash award of $50 for the best paper presented to the Junior Academy. Mark Whitman will be notified.
> A report on the assets of the Foundation from Frank Guthrie shows all is well.
> Several aspects of the Michigan and Ohio Academies might be worth our consideration. A trip to Columbus to visit the Ohio academy office could be profitable.

The status of Fellows who are no longer active members has long been a question. It was decided that this year's Directory will list only those Fellows who are active or emeritus members.

Schmidt announced that the *Newsletter* will be issued soon, for the first time since October. There will be four issues this year.

One of the most difficult duties of an incoming President is the appointment of committees. In a wide-ranging discussion of how this task might be expedited, suggestions included formation of a Committee on Committees, getting information from section chairs, using the Executive Committee to advise the President and eventually assigning some of the responsibility to the Liaison Officer. Until such mechanisms can be set up, duties of committees will be described in the *Newsletter,* and a call for volunteers made. A questionnaire may be sent out with the dues notices, with a return card. A goal would be to have committee chairs selected by the time of the Fall meeting, and for them to suggest members to the President so the committees could be appointed shortly after January 1. To facilitate work of the committees, the Program Chair should consider specifying a time at each meeting for the committees to meet.

As they are now being done, there is too much overlap between the meetings of the Executive Committee and the Council, and too little opportunity for the members of the Council to consider legislation before they are asked to vote on it. This year the Executive Committee will meet several weeks before the Spring and Fall meetings, and letters will be sent to Council members informing them of issues to be discussed. The general membership will also be informed through the *Newsletter*.

Turning to the question of the Executive Secretary or Liaison Officer, Burden reported on the January 25 meeting of the Directors of Science Education Foundation of Indiana, Inc. (SEFI), at which Ray C. Paschke was appointed Executive Director. After a discussion of what this appointment might mean to relations between IAS and SEFI, it was decided to invite Mr. Paschke to attend the next Executive Committee meeting to discuss his plans and how he believes the two organizations might relate. The next step the Academy needs to take is to begin a search for candidates for our position. This could be done through the *Newsletter*, the Corporate Relations Committee, direct appeals to universities, etc.

Jones moved that Science Club dues and their registration fee at the Annual Meeting be merged so that each club plays one $10 fee. The motion carried.

Jones moved that the Science Education Advisory Committee be requested to determine what interest there would be in scheduling a meeting in the Spring, sponsored by the Academy, for the purpose of presentation of papers by undergraduate students from colleges and universities. The motion carried.

Jones circulated copies of bids from two jewelers for pins using the new logo. They will be discussed at the next meeting.

The next meeting will be held somewhere in Indianapolis at 1:00 p.m. Thursday, March 31.

The meeting was adjourned at 2:30 p.m.

Respectfully submitted,
Richard L. Conklin, Secretary

EXECUTIVE COMMITTEE MINUTES OF MEETING AT THE INDIANA STATE LIBRARY

April 16, 1988

The meeting was called to order at 10:00 a.m. All members were present except for the Secretary; these minutes are compiled from notes made by the President.

Minutes of the Executive Committee meeting of February 6, 1988, as distributed by the Secretary, were approved.

The President distributed copies of a letter written to Karl Kaufman. This letter expressed the hope and need for improved communication and cooperation between SEFI and the Academy; noted the new Executive Secretary of SEFI, Ray Paschke, would be extended an invitation to present his views and plans to the Executive Committee at the first favorable opportunity; and extended Paschke an invitation to join the IAS.

Considerable discussion ensued about the SEFI-IAS relationship. Stan Burden reported on the SEFI Council meeting of the previous day, April 15, which he attended as proxy for the IAS president. During the following discussion, it was noted that four of the five most active and productive Science Fair directors will not be continuing in this role next year, and that the IAS Consitution contains a section regarding responsibility of the IAS in appointment of such directors.

The remainder of the session was devoted to refining and improving the statement outlining the "duties" of the to-be-appointed "Executive Liaison Officer" for the IAS, as moved and approved by the Council at the Fall meeting on November 5, 1987. The consensus of the Executive Committee was that an initial appointment probably should be in the form of an individual contract of stated duration, rather than advertising at this time for a permanent appointment, thus avoiding a wide variety of complex issues and problems involving state and federal hiring procedures, fringe benefits, etc. The approved aims and objections statement ("job description") will be presented for action to the Council at St. Mary's on April 21.

President Melhorn reported briefly on recent contacts with the respective Executive Directors of the Michigan Academy and Ohio Academy. Preliminary interchange clearly indicates that state academies tend to share common problems and suggests that more abundant and frequent contacts should be maintained in order to mutually address the most pressing issues. An overnight trip is planned in early June to Columbus, for the purpose of having more in-depth discussions with Mr. Lynn Effner, Executive Director of the OAS.

INDIANA ACADEMY OF SCIENCE SPRING MEETING OF THE COUNCIL

April 22, 1988

MINUTES

The meeting was called to order by President Wilton Melhorn at 2:00 p.m. in the Cushwa-Leighton Library of St. Mary's College, Notre Dame, Indiana.

Minutes of the Fall Meeting were approved.

TREASURER'S REPORT

Duvall Jones presented the financial report, January 1 to April 22.

	Academy Accounts	Administered Accounts	Total
Balance: January 1, 1988	$14,612.73	$28,673.88	$43,286.61
1988 Income	5,994.46	50,302.06	56,296.52
1988 Expenditures	6,389.54	44,740.28	51,129.82
Balance: April 21, 1988	$14,217.65	$34,235.66	$48,453.31

Summary of Trust Funds

Anticipated income and expendable funds	
Academy Fund	$ 3,000.00
John S. Wright Fund	52,000.00
Invested Income Account	120,000.00
Approved expenditures	$ 90,600.00

Membership Report

708 members for 1988 as of April 22
652 on file from 1987 but not paid for 1988
40 new and reinstated members in 1988
180 members and clubs dropped for nonpayment of 1987 dues
The report was approved.

REPORTS OF ELECTED COMMITTEES

Academy Foundation

Ernest Campaigne reported the status of the accounts as of March 31, 1988.

	Approximate Market Value	Estimated Annual Income	% Yield
John S. Wright Fund	$1,319,265.41	$54,949	4.17
Invested Income Acct.	120,085.07	7,635	6.36
Academy	51,926.79	3,161	6.09
	$1,491,277.27	$65,745	4.41

Research Grants

Melhorn reported a call from Research Grants Chair Wilson Lutz to the effect that nineteen proposals had been received and $10,000-$12,000 would be awarded. [The list of grants was received by the Secretary after the meeting and is appended to these minutes.]

The members of the committee have been polled to determine if they would approve using some Grant funds in support of the Executive Liaison Officer. Three said yes; two were undecided.

REPORTS OF STANDING COMMITTEES

Program:

Co-chair Richard Jensen urged that a *Newsletter* be published for distribution of Abstract forms well before the Fall meeting.

Fellows:

Chair William Gommel reported that committee members have been contacted. Melhorn suggested that the committee should consider carefully the question of criteria for the rank of Fellow. The *Newsletter* should include a note inviting nominations. It was suggested that Jones provide committee members with a list of members of the Academy by years of membership, and that the list of twenty-year or more members be published in the *Newsletter.*

Emeritus Members:

Chair Robert Cooper reported by letter that only one application had been received and that the applicant is not yet eligible.

Invitations:

Manchester College has presented a formal invitation to act as host for the 1990 meetings. Benjamin Moulton moved that the Council support the Committee on Invitations when it approves that site. The motion carried.

Library:

Chair Holly Oster reported that Western Newspaper Publishing has delivered 1000 copies of Monograph 5: *Endangered and Threatened Vertebrate Animals of Indiana*, by John O. Whitaker, Jr. and James R. Gammon. Approximately 500 copies will be mailed to exchange partners and Indiana libraries together with Volume 96 of the *Proceedings* and *Butterflies of Indiana.*

Publications:

Chair Benjamin Moulton reported that Monograph 5 is available for purchase.

Of 2000 copies of *Butterflies of Indiana*, 1111 have been sold by Indiana University Press, 500 are being distributed by the Library, and 400 are to be sold by the Academy. Brief mention was made of the possibility of increasing the price of the book.

The committee hopes to send a brochure to high school libraries and others who might be interested, describing Academy publications and how they may be purchased.

There was some discussion of the timing of meetings of the committee, the hope being that they might be sufficiently in advance of Council meetings that results of the deliberations could be reported to the Council.

Speaking for the committee, Moulton moved that each chair of a Section be responsible for recommending to the Editor which presentations are to be published in the *Proceedings* as abstracts and noted by title only. Upon motion by Campaigne, this motion was referred to the Publications Commimittee for further study.

William Eberly moved that for the Annual Meeting in 1988 the Academy will publish abstracts in the *Proceedings* accordance with past practice. The motion carried.

The committee reported approval of a policy permitting any University-Press or author seeking support for a publication to submit a request for such support, provided that the press is in Indiana and the authors are Academy members. Guidelines for committee deliberations on such requests have been established. No Council action was requested.

The committee recommends that it and the Editor be consulted as to all official publications of the Academy, with a view toward increasing the indetifiability and the uniform quality of such publications.

Science and Society:

Chair Edwin Squiers reported that the committee has agreed to act as a cosponsor with the Indiana Committee for the Humanities to support the modification of the exhibit *Charles Darwin, a Portrait Biography* to enable it to tour throughout Indiana. The premiere showing will occur at the Fall meeting of the Academy.

The 1988 Fall Symposia will focus on the state of science education in Indiana. One might revolve around an assessment of the ISTEP tests. A second symposium will deal with the integration of high-technology systems into the educational process.

Youth Activities:

In a printed report, Chair Virginia Rhodes called attention to the Science Talent Search, held March 4-5, and the Science Olympiad, held March 12. The third Hoosier Science and Engineering Fair was held at Children's Museum in Indianapolis on April 14-16 with 72 students participating. The Academy provided financial support in the amount of $3,000 to the twelve regional science fairs. The report also included names of winners of several awards presented by the Junior Academy of Science.

Jan Woerner, Director of the Indiana Science Olympiad, described that program and showed a videotape of some Olympiad events. She urged the Academy to help by encouraging members to volunteer to help set up and judge events, and to provide funds to help teachers go to training events. By such support the Academy can show that it appreciates the importance of pre-college science education.

Corporate Relations:

Chair E. Campaigne reported two objectives the committee has established: 1) to increase corporate membership in the Academy; and (2) to increase individual memberships among industrial scientists.

Membership:

Chair Charlotte Boener reported several steps that have been taken to attempt to expand membership. They include enlisting the help of emeritus members and section chairs, and sending letters to people who have recently failed to renew their membership.

Speaker of the Year:

Chair John B. Patton sent a list of the appearances of Dr. Samuel A. Rhine, speaking on "The New Genetics: Applications and Implications for Our Future." He has spoken nine times. The Secretary was instructed to write a letter of appreciation to Dr. Rhine.

Editor:

Editor Donald Winslow sent a breakdown of the contents of Volume 97 of the *Proceedings*. It reflects a total of 208 section presentations, 56 of which were published in full.

Committee on Awards (ad hoc):

Chair Marvin Carmack presented the final report of this committee, It suggests several possibilities:

(1) Continue the single designation of Fellow, with emphasis on research productivity and service to the Academy.
(2) Use the category of Honorary Member to honor an individual who has made significant contributions to Indiana science and has not necessarily been a member of the IAS.
(3) Create new awards, for example, a Hoosier Research Prize for an outstanding research achievement.
(4) Make special efforts to have outstanding members of the Academy nominted for recognition by other scholarly organizations at the state and national level.

Each of the above reports was approved after presentation.

OLD BUSINESS

President Melhorn presented a description of the position of Executive Liaison officer, as prepared by the Executive Committee.

Title of Proposed Position

Executive Liaison Officer

Objectives

Although a broad variety of aims and goals might be listed and defined, ultimately the success of the office must depend largely on the interests and capabilities of the appointee. The final success of the appointment can be measured by:

1. An increase in IAS membership.
2. A more positive public image.
3. An increase in external monetary contributions which will improve and expand Academy programs.

The appointee shall implement the directives of the Executive Committee. The Executive Committee will annnually review and evaluate the performance of the appointee, and the appropriateness and scope of the duties assigned.

Duties

1. Promote the aims, interests, and goals of the Academy as outlined in the Academy Constitution.
2. Identify worthy activities proposed or conducted by other state and regional organizations, and facilitate participation of the IAS in these activities as deemed appropriate.

3. Aid in writing proposals and make contacts seeking funds to support Academy activities and interests.
4. Identify and facilitate the role of the Academy in support of museums, science education, youth activities, and conservation efforts, as well as communicate the programs of the Academy through the appropriate public media.
5. Provide continuity and efficency in the execution of Academy business.
    a. Be responsible for facilitating the timely and cost-effective publication and mailing of the *Programs and Abstracts* for the Fall meeting, and programs for the Spring meeting, in conjunction with the Program Chair(s).
    b. Assist the incoming President in the selection of committee chairs.
    c. Develop and keep updated a "Manual of Operations" for Academy officers and section chairs, and assist in administration of operational policy.
    d. Other responsibilities as agreed upon in consultation with the Executive Committee.

After approval of the job description (as amended, if necessary) the position will be announced and candidates sought.

William Eberly moved approval of the above statement of objectives and duties of the Executive Liaison Officer. The motion carried.

NEW BUSINESS

Jones spoke to the establishment of an Undergraduate Research Symposium to give seniors an opportunity to describe their research before being graduated from college or university. John Ricketts of DePauw has offered to organize such a symposium, with costs to be borne by the host institution. Squiers moved that the Academy endorse the concept of such a symposium in the Spring of 1989 and pursue the possibility of co-sponsorship. The motion carried.

ADJOURNMENT

The meeting was adjourned at 6:00 p.m.

Respectfully submitted
Richard L. Conklin
Secretary

ADDENDUM
INDIANA ACADEMY OF SCIENCE
RESEARCH GRANTS COMMITTEE

Fall 1988, Grant Applications Funded

Principal Investigator	Title	Award
Antolovic, Zorka IU Bloomington Zoology	Deposition Setting and Diagenetic History of the Haney Limestone: Sulphur, Indiana	$362
Dini, Michael L. Notre Dame Biology	Effects in Varying Resource Availability and Visible Predation Pressure . . . Among *Daphnia*	738
Etchberger, Cory R. IU Bloomington Biology	Study of Sexual Dimorphism and Geographic Variation of Temperature Sex Determination in Turtles	538
Hicks, David J. Manchester Biology	Factors Affecting the Composition and Dynamics of Forest Remnants in Wabash County, Indiana	848
Jarial, Mohinder S. Manchester Biology	Factors Affecting the Composition and Dynamics of Forest Remnants in Wabash County, Indiana	563
Ma, Pang Fai Ball State Medical Ed.	Developmental Changes of Adenosine Deaminase in Frog Tadpoles	732
Magej, Robert F. IU Bloomington Biology	Territoriality and Agonistic Behavior of Plathodontid Salamanders: Field Studies of Behavior . . .	422
Marr, Jackson L. Southern Indiana Science & Math.	Resource Partitioning by Freshwater Turtles	603
Mays, Charles E. DePauw Biology	Effects of Passive Smoke on Murine Reproduction and Development	528
McGrath, Dennis J. Nature Conservancy Field Office	Recovery Analysis of a High Bluestem-Little Bluestem-Indiangrass Prairie in White County, Indiana	425

INDIANA ACADEMY OF SCIENCE RESEARCH GRANTS COMMITTEE

Summer, 1988, Grant Applications Funded

Principal Investigator	Title	Award
Richeson, Mary Lee IU PU Fort Wayne Biology	Effect of Dietary Fats on Differentiation in Strain A/ST Mice	$1300
Samuelson, Alan C. Ball State Geology	Radon and Other Trace Elements in Indiana Groundwater	530
Sipe, Betty Burns Ball State Biology	Investigation of Relationships Between Teaching Strategies of High School Biology Teachers . . .	338
Squiers, Edwin R. Taylor Bio. and Environ.	Computerization of the Long-term Data Base from the Devon Project . . .	648
Tuncay, Atitla IU Gary Chemistry	Hypervalent Iodine in Orgnanic Synthesis	710
Urbano, Charissa M. Ball State Biology	Dose-response Analysis of the Teratogenic Interaction of Caffeine and Acetazolamide in C57BL/6J Mice	930
Vispo, Conrad Indiana State Life Sciences	Effects of Thermoregulation on the Behavior of Wild Thirteen-lined Ground Squirrels . . .	511
Xu, Lei Notre Dame Biology	Hormonal Control of Thermal Hysteresis Antifreeze Proteins in Freeze Susceptible Insects	992
Yoon, Stacia L. IU Bloomington Biology	Proximate Mechanisms of Female Choice in the Gray Tree Frog, *Hyla chrysocelis*	313

Total Amount Awarded: $12,031.00

INDIANA ACADEMY OF SCIENCE MEETING OF THE EXECUTIVE COMMITTEE

September 10, 1988

The meeting was called to order by President Wilton Melhorn at 9:15 a.m. in the Indiana State Library. Voting members present were Charlotte Boener, Stanley Burden, Richard Conklin, Duvall Jones, Wilton Melhorn, and Donald Winslow. Holly Oster was also present during much of the meeting.

During the morning the persons who had volunteered to serve as Editor of the *Newsletter* were interviewed and discussed. William McKnight of the Indiana State Museum and Granville C. Kyker of Rose-Hulman Institute each spent about an hour with the committee. Gene Kritsky of the College of Mt. St. Joseph was unable to attend, but sent a letter reiterating his willingness to serve and answering some questions. After considering other business, it was agreed that a decision should be made if possible. After all members had given their impressions of the men, a vote was taken. The result showed that four favored one candidate. The President abstained, and Burden was no longer present. Before the decision is final, Kritsky will be invited to talk to the committee. The new Editor is to begin with a January, 1989, issue.

Melhorn briefed the group on matters arising since the Spring meeting:

A letter printed in *The Indianapolis Star* raised the possibility that the Indiana State Museum might moved to a new building in White River Park, and that the new facility might provide space for the Academy. Melhorn and Boener have attended a meeting about this and agree that the Academy should have a plan available as soon as possible in case an invitation to submit one comes during discussion at some level of government.

Frank Guthrie will represent the Academy at a Research Corporation seminar in Los Angeles.

Boener has requested committee chairs to submit reports for the Fall meeting by October 1. Some have; the others will be reminded.

Science Talent Search has been moved to Bloomington because the IU Union Building in Indianapolis has been closed. Alfred Schmidt will co-chair the Talent Search.

After some hesitation, Robert Cooper has agreed to continue to serve as Chair of the Committee on Emeritus Members until the end of 1988.

The Youth Activities and Publications Committees and the *ad hoc* committee on publications review met during the summer. Winslow recommends that there be co-chairs for the Y.A.C. and some of its subcommittees.

Winslow and Oster have prepared the budget request to the State. Tri Kappa has given $3,500 and Public Service Indiana $1,000 to the Science Talent Search. AAAS has given the Junior Academy $1,200.

Pins and T-shirts bearing the IAS logo are being ordered for sale at the Fall meeting.

Jones presented the tentative program for the December 3 Symposium dealing with Science Education. At this point Carole Goshorn of Columbus, President-Elect of Hoosier Association of Science Teachers, Inc., joined the meeting because HASTI will be a co-sponsor of the Sympoisum. Jones explained the program, described briefly the presentations to be made by several speakers of national reputation, and introduced the proposed budget. Melhorn opened a discussion of who might be expected to attend the program and how it would be publicized.

The proposed budget showed anticipated expenses of $4,500 and identified income of $3,500, $1,000 of which was to come from $10 registration and lunch fee. It was agreed that the $10 should be increased to $15. There was considerable uneasiness about underwriting a project with such a large anticipated deficit, but some argued that the Academy is committed to sponsoring the event. Boener moved that the Executive Committee support the Science and Society Committee in its sponsorship of the Symposium, encouraging them to solicit co-sponsors who might be willing to make financial contributions, but recognizing that the Academy might need to allocate money to cover a shortfall. The motion carried, with two abstentions.

Noting that the Publications Committee has adopted the CBE Style Manual and that this might be unavilable to many members, it was recommended that the important things for authors to know be abstracted and printed in the *Newsletter* each year. Winslow agreed to provide such an abstract for the October *Newsletter*.

Melhorn introduced a letter he and Boener received from John Gallman of the Indiana University Press asking if the Academy would divide the cost and royalties from a new book on wildflowers of Indiana. Melhorn will inform him that the Academy has no uncommitted funds.

At the Fall meeting the Academy voted to support in principle a Symposium on Undergraduate Research to be held at DePauw University, with costs to be underwritten by the host institute. Plans have changed so the Symposium will be held at Butler University. A letter from Wendell Berry outlines a budget of $2,000 and asks the Academy to underwrite half. The Symposium would involve 1989 funds. Its sponsors will be invited to submit a proposal to the Budget Committee and to appear at the meeting of that comittee to make a very short presentation if they so desire.

Duvall Jones asked permission to send to candidates for public office, on behalf of the Academy, questions on matters related to science and science education. The questions and responses would be published in the October *Newsletter*. Boener moved that the Executive Committee support Jones in asking the questions and publishing the responses. The motion carried.

The meeting of the Budget Committee was set for December 10.

The time of the Executive Committee meeting at the Fall meeting will be 9:00 a.m. to 2:00 p.m.

This committee will meet again Saturday, September 17, at 9:00 a.m. at the State Library. The major agenda item will be the Executive Liaison Officer.

The meeting adjourned at 4:00 p.m.

Richard L. Conklin
Secretary

INDIANA ACADEMY OF SCIENCE MEETING OF THE EXECUTIVE COMMITTEE

September 17, 1988

The meeting was called to order by President Wilton Melhorn at 9:00 a.m. in the Indiana State Library. Members present were Charlotte Boener, Stanley Burden, Richard Conklin, Duvall Jones, Wilton Melhorn, and Donald Winslow (Winslow was excused after the first item of business was completed).

Gene Kritsky of the College of Mount St. Joseph, who was unable to attend the September 10 meeting, was interviewed as a volunteer to edit the *Newsletter*. After his departure and some discussion, Conklin moved that Kritsky be appointed Editor of the *Newsletter*. The motion carried unanimously. Melhorn will inform him of his selection and ask that he begin after publication of the October *Newsletter*.

During the interviews of William McKnight and G. C. Kyker, areas came to light in which their abilities could be used even better by the Academy than in the *Newsletter* position. When Melhorn inform them of the choice of Editor, he will thank them for volunteering and will offer them other opportunities to serve the Academy.

Minutes of the meeting of September 10 were discussed and approved with some modifications.

The Budget Committee meeting on December 10 will be held in the Auditorium of the State Library.

Melhorn and Boener reported conversations with George Gard, whose firm prints the *Proceedings*, addressing problems of delays in publication time and quality of printing. Such problems are not yet fully resolved for Volume 96. Burden offered the following motion: The Executive Committee recognizes that final decisions on publication matters rest with the Editor. However, the committee recommends that the Editor consider accepting Volume 96 despite some imperfections, and negotiate with the printer a reduction in cost if this seems appropriate. This recommendation is made to reduce further delay in distribution of the volume. The motion carried.

The remainder of the meeting was spent in discussing criteria for selecting the Executive Liaison Officer (ELO). A point which needs to be clarified is whether the ELO is to be an employee of the Academy or if the arrangement under which the ELO serves will be a contractual one. The matter is important because the paperwork and payment would be quite different under the different arrangements. Jones will consult an attorney to determine legal implications. Melhorn will draft an announcement describing the qualifications sought and inviting members to indicate their interest in becoming ELO. After the draft has been circulated and approved by the Executive Committee, it will be reproduced and mailed by Conklin to all members of the Academy.

The meeting was adjourned at 12:35 p.m.

Richard L. Conklin
Secretary

NOTE: A discussion of the office of Director of Public Relations was part of the interview and subsequent consideration of the Committee. It was agreed that this would not become part of the public record until the President had clarified the status of Alfred Schmidt, who has not resigned from the position but has not been fulfilling the duties thereof.

INDIANA ACADEMY OF SCIENCE
MEETING OF THE EXECUTIVE COMMITTEE

November 10-11, 1988

The meeting was called to order by President Wilton Melhorn at 9:00 a.m. at the Ramada Inn, South Bend, Indiana. Members present were Charlotte Boener, Stanley Burden, Richard Conklin, Duvall Jones, Melhorn, and Donald Winslow.

Minutes of the meetings of September 10 and 17 were approved as corrected.

The office of Director of Public Relations was discussed. It will be dealt with further at the meeting of the Council.

The *ad hoc* Publications Review Committee met with the President and the Editor on August 26 to discuss their charge. Chair William McKnight sent a memorandum on September 14 suggesting another meeting. It is hoped that the committee will have a report for the Academy at the Spring meeting.

John Gallman, Director of the Indiana University Press, met with the Executive Committee to discuss ways in which the IU Press and the Academy might cooperate in the publication of several books of particular interest to the people of Indiana and with possibly wider readership. Joint publication by the two entities could call for a considerable commitment of funds by the Academy and reconsideration of the Academy's philosophy of publication. The next step would appear to be a meeting at the end of February, 1989, of Mr. Gallman with the Executive and Publications Committees of the Academy. Such a meeting might lead to a proposal to be discussed by the Council at its Spring meeting. In 1989 the Budget Committee may need to consider long-range planning suggestions of the Publications Committee.

The Corporate Relations Committee has suggested a public relations campaign. Scott Litherland of Bristol-Myers Corporation, a member of that committee, introduced Anne Z. Rogers to present public relations and other program recommendations she had prepared for the Academy. Before she began, Litherland explained the need for professional expertise in making the public aware of a product or organization and described Rogers' credentials. She then described her proposals in detail and responded to questions about the items and the probable cost to the Academy.

The meeting was recessed at 1:15 p.m. and reconvened at 7:45.

The President has received a letter from Section Y of the AAAS asking for an application for membership and appointment of a delegate. The President will respond and ask for clarification of the status of the transfer from Section X to Section Y.

There followed a long discussion of the ramifications of employing an Executive Liaison Officer (ELO) and a professional public relations person in addition to a revitalized office of Director of Public Relations. During this discussion, Winslow was excused from the meeting. When a list was made detailing the services the Academy could use and their allocation, it seemed clear that this was a fruitful direction. Conklin moved that the Executive Committee proceed to implement the employment of an Executive Liaison Officer and a public relations firm and the coordination of their work with the Director of Public Relations, with the duties divided as detailed on the aforementioned list. The motion carried unanimously. Of the $15,000 allocated to the office of ELO, it seemed that a reasonable division would be $5,000 for ELO and $10,000 for Public Relations.

Members of the Committee reviewed the dossiers of seven applicants for the position of Executive Liaison Officer. After discussion, there was unanimous consent that the position be offered to Dr. Donald Winslow.

Burden agreed to talk to Winslow and Rogers on Friday morning to determine if they were still interested under the new terms. If so, the Committee will meet with them before dinner.

The meeting recessed at 10:30 p.m. November 10.

The meeting reconvened at 5:15 p.m. November 11 in the Dining Hall at St. Mary's College. The full Executive Committee was present, including Gene Kritsky, the new Director of Public Relations. Scott Litherland and Anne Rogers were also present. Incoming President Charlotte Boener presided.

Burden reported that Donald Winslow had agreed to serve as Executive Liaison Officer. Anne Rogers is interested in serving the Academy, but needs to think through which services she should be asked to perform to make the most effective use of the money available for the position. When the Budget Committee meets December 10 she should be able to present a new cost analysis.

There was some discussion of possible problems in dividing responsiblities between Kritsky and Rogers and between Winslow and Rogers. It was agreed that although the line of authority and responsibility will be drawn carefully, all three people will need to be flexible as the new structure takes shape.

The next meeting of the Executive Committee will be after the Budget Committee meeting on December 10 at the State Library, probably after noon.

The meeting adjourned at 6:10 p.m.

Respectfully submitted,
Richard L. Conklin, Secretary

INDIANA ACADEMY OF SCIENCE
FALL MEETING OF THE COUNCIL

November 10, 1988

The meeting was called to order by President Wilton Melhorn at 2:40 p.m. in the Rotary Room of the Dining Hall at St. Mary's College, Notre Dame, Indiana. Approximately thirty-five members of the council were present.

Minutes of the Spring meeting of the Council were corrected and approved as corrected.

President Melhorn announced that the position of Director of Public Relations was vacant, and that Gene Kritsky had been appointed to that post.

TREASURER'S REPORT

Treasurer Duvall Jones gave the financial reports.
Summary of finances:

	Academy Accounts	Administered Accounts	Total
Balance: January 1, 1988	$14,612.73	$28,673.88	$ 43,286.61
1988 Income	14,369.67	96,421.71	110,791.38
1988 Expenditures	9,807.00	87,622.59	97,429.59
Balance: November 8, 1988	$19,175.40	$37,473.00	$ 56,648.40

Membership as of November 8, 1988: 1121, including 44 clubs

COMMITTEE REPORTS

Several committee reports have been submitted by mail. Richard Jensen moved approval of all such reports, except for obvious corrections. The motion carried. Summaries of these reports will be given where appropriate.

REPORTS OF ELECTED COMMITTEES

Academy Foundation (E. E. Campaigne for Chair Frank Guthrie)

	Value as of Nov. 7	1988 Income
Academy Found. Acct.	$ 55,457	$ 3,410
John S. Wright Fund	$1,368,335	$55,971
Invested Inc. Account	131,827	9,454
	$1,555,619	$68,835

Research Grants (Jones for Chair Austin Brooks)

Grants in the amount of $33,000 have been awarded in the Fall round. A list of grants is appended to these minutes.

REPORTS OF STANDING COMMITTEES

Biological Survey and Natural Areas (John Bacone)

The committee is concerned about loss from Indiana of valuable biological collections, and has suggested that the President write a letter urging the retention of such collections.

The President has received a letter from member John Schrock containing resolutions regarding reduction of the number of faculty members in field-oriented specialties. The letter has been sent on to the Committee on Resolutions.

Editorial Board (Donald Winslow)

In 1983, the Executive Committee made provisions for two $150 awards to encourage better research. The following manuscript was selected by the Editorial Board for an IAS Research Award to be presented at the Fall meeting: Jocelyn E. Dunphy and Kenneth L. Busch, Department of Chemistry, IU, Bloomington, *Chromatography/SIMS: Applications to Peptides and Bile Acids*. The paper will be published in volume 97 of the *Proceedings*. A ballot for nominating other papers was included in the October *Newsletter*.

The long-overdue Volume 96 of the *Proceedings* was delivered by the printer on October 1. It contained errors which made it unacceptable to the Academy. It was returned for corrections.

The Publications Committee has adopted the current edition of the *CBE Style Manual*, published by the Council of Biology Editors, Inc., as the official guide for authors of the Academy's publications. Manuscripts not prepared according to its guideliens will not be accepted for review by the Editorial Board.

Emeritus Members (Melhorn for Chair Robert Cooper)

Four members were nominated for Emeritus Membership. They were approved by the Council for presentation at the General Meeting.

Program (Richard Jensen)

The By-Laws of the Academy should be more specific as to the days and structure of the Fall meeting. Where there are ambiguities, the Program Chair can be placed in a difficult position. Parliamentarian William Eberly responded that the Program Chair is responsible for the schedule of the meeting. Details should be set forth in a manual of operations, but there is no need to change the By-Laws.

Fellows (William Gommel)

Seven members were nominated for the rank of Fellow. They were approved by the Council and will be presented to the members at the General Meeting.

New lapel pins are available for all Fellows.

Thanks should be extended formally to Dr. Ralph Seifert of Hanover College for his years of service in lettering the certificates presented to Fellows.

High School Teacher Research

Frank Guthrie sent a report of a conference on "Enriching Science Teaching Through Research," sponsored by the Research Corporation. The emphasis of the conference was on the importance of teaching science at the secondary school and junior college levels, especially to non-science majors. The Research Corporation is sponsoring 5,000 grants to teachers in the Southwest. Guthrie suggested that the Academy give support for a more ambitious program than we currently have.

Invitations

The 1989 meetings hosted by Indiana University Southeast will be April 14-15 at Clifty Falls State Park and November 9-11 on the New Albany campus.

In 1990, Manchester College will serve as host to a symposium on April 20. The Fall meeting will be there in late October or early November.

Invitations are needed for 1991.

Indiana Science Talent Search (Winslow)

Plans are under way for the 1989 search. Public Service Indiana and Tri Kappa have agreed to continue their financial support. The Honors luncheon will be held at the IU Union Building in Bloomington on March 3-4. An Associate Director will be appointed to share the responsibilities of administration, and additional corporate sponsorship may be needed.

Junior Academy of Science (Mark Whitman)

The general state meeting is at St. Mary's College today. Students are presenting papers based on their research, are participating in problem-solving competition, and are presenting five-minute talks on the topic "What must the U.S. do to remain technologically competitive in the twenty-first century?"

On December 10 the Junior Academy will meet at the University of Indianapolis to select the Outstanding Student Paper Presenter and the Outstanding Student Delegate from finalists selected on November 11. A student selected as the Outstanding Junior Scientist and the student's sponsor will be sent to the AAAS meeting in San Francisco.

Library (Holly Oster)

Volume 96 of the *Proceedings* was received from the printer and mailed to members in October. Sixty-eight hard cover volumes were sent to Indiana academic and public libraries.

During fiscal 1988, 137 volumes were added to the library's collection, bringing the total to 11,612 volumes. Interlibrary loan requests totaled 407, a 32 percent increase over 1987.

"Advice of Allotment" of $8,900 was received from the State Budget Agency in July. This will be applied to the cost of printing Volume 97 of the *Proceedings.*

Membership (Charlotte Boener)

Letters have been sent to emeritus members, section chairs, and Membership Committee members urging them to encourage others to join the Academy. Letters were also sent to a selected group of people who did not renew their memberships. The University of Southern Indiana reported that their Mathematics and Science departments have achieved 100 percent membership for all full-time staff.

Nominations (Benjamin Moulton)

A slate of officers was presented. Campaigne moved that the slate be presented to the membership at the General Meeting. The motion carried.

Publications (Moulton)

Endangered Species of Indiana by Whitaker and Gammon was published in early Spring. 1,000 copies were printed; approximately 500 remain.

Of the 5,000 copies of *Butterflies of Indiana,* approximately 2,200 have been sold.

Flora of Indiana, by Crankshaw, should be in press in December. Two new projects on wildflowers and on shrubs of Indiana have been proposed.

The committee approved a proposal to reduce the inventory of monographs, etc., by offering them for sale at reduced prices.

A procedural manual of operations was approved by the Committee and distributed to the Council.

Resolutions (William Davies)

Two resolutions have been developed by the Science Education Advisory Committee, reviewed by the Resolutions Committee, and published in the October *Newsletter*. Their full texts are recorded in the minutes of the General Meeting. Resolution #1 concerns the need for changes in educational proficiency statements and Indiana Statewide Testing for Educational Progress (ISTEP). Resolution #2 deals with the need for improved working conditions for secondary science teachers. At issue in the Council meeting is not the content of the resolutions, but whether they should be presented to the membership for discussion and vote at the General Meeting.

Jones moved that Resolution #1 be approved for presentation. The motion carried by voice vote.

Jones moved the Resolution #2 be approved. The vote was 9 in favor, 5 opposed, 15 abstentions. The parliamentarian ruled that the motion had won.

Science and Society (Edwin Squires)

A written report mentioned the committee's assistance in obtaining support for the exhibit "Charles Darwin and the Evolving Humanities." Full credit for the exhibit belongs to Gene Kritsky.

The Fall Symposium, "Science Education at the Crossroads," will be a joint activity of this committee and the Science Education Advisory Committee. Duval Jones urged members to attend.

Preliminary discussions are under way for a spring workshop in the use of computer technology to extend science literary in school systems.

Science Education (Duvall Jones)

The major activities of the committee have been the preparation of the Resolutions and the Symposium, which have been reported above.

Speaker of the Year (Stanley Burden)

Burden and Campaigne both commented on the fact that the By-Laws require the selection of the Speaker of the Year by June 1, but recently the selection has been later than that. June 1 should be honored; later selection causes scheduling problems.

Youth Activities (Virginia Rhodes)

The written report discusses the Junior Academy and the Science Talent Search, which have been covered above. The Indiana Science Olympiad, directed by Jan Woerner, will be held on March 11, at a site to be determined.

The fourth annual Hoosier Science and Engineering Fair will be held April 13-15, 1989, at the Children's Museum in Indianapolis. Ray Paschke, Executive Director of the Science Education Foundation of Indiana, will coordinate the event.

A grant of $1,200 was received from AAAS for the support of high school science research projects. The Research Committee awarded grants in September.

Campaigne focused attention on the comment of the Junior Academy Director that he is operating autonomously, although the Constitution calls for an Advisory Committee appointed by the President of the Academy. There was discussion of the advisability of changing the Constitution to fit the style of the Director. The Youth Activities Committee was asked to study the matter and report its findings to the Council.

Corporate Relations (E. Campaigne)

At a committee meeting held on October 1, there was general agreement that Academy public relations are at a very low ebb. Scott Litherland, a member of the committee, outlined the requirements for a successful public relations program, and recommended that a professional public relations person be asked to develop a proposal with general program objectives and a reasonable budget. He volunteered to contact such a person and arrange for a presentation to the Executive Committee and/or Council at the Annual Meeting on November 10. The committee approved this action, and the Executive Committee has been contacted.

OLD BUSINESS

Melhorn reported on the status of the Undergraduate Research Symposium, which was endorsed in principle at the Spring meeting of the Council. There will be such a symposium at Butler University on April 21. Butler will underwirte the full cost, but they wish formal endorsement by the Academy, and permission to use the name of the Academy "in association with" Butler University. The Secretary was directed to write a letter to that effect. Kritsky suggested that the Academy might award prizes for the best papers; this would be a matter for Budget Committee action.

The search for Executive Liaison Officer is in progress. A general call has been sent out, and there have been several responses.

NEW BUSINESS

Eberly has reviewed the Constitution and could suggest some improvements. It was agreed that such a review should be carried out by the Committee on Amendments, whose charge is to review the wording of amendments submitted by members. Desired amendments should be sent to that committee. If they are to be voted on at the Fall 1989 meeting, they need to be in the hands of members 30 days before that meeting.

The meeting was adjourned at 5:05 p.m.

Respectfully submitted,
Richard L. Conklin
Secretary

INDIANA ACADEMY OF SCIENCE GENERAL MEETING

November 11, 1988

The meeting was called to order by President Wilton Melhorn at 1:20 p.m. in O'Laughlin Auditorium at St. Mary's College.

Dr. William Hickey of St. Mary's College welcomed the Academy and gave a "thumbnail sketch" of the college, emphasizing the importance of science in St. Mary's curriculum.

Dr. Dorothy Feigl, Dean of the College, spoke of the value of the Junior Academy as an experience that encourages young people in the study of science, and the Academy as a bringing together of scientists to share thoughts. She also emphasized the commitment of St. Mary's College to science teaching and research.

Benjamin Moulton, Chair of the Committee on Nominations, presented the following slate of officers for 1989:

President: Charlotte Boener
President-elect: Wendell McBurney
Secretary: James Haddock
Academy Foundation: Max Marsh
Bonding Committee: Benjamin Miller
Research Grants Committee: David Chesak

A motion by E. Campaigne, those nominated were elected unanimously.

Necrologist Fay Kenoyer Daily read biographical sketches of the following Academy members whose deaths were recorded in 1988:

A. Lee Caldwell
Felix Michael Haurowitz
Donald P. Hazlett
Robert L. Kent
Alfred Herman Meyer
John B. Patton
Charles P. Warren
Grant T. Wickwire

A moment of silence was observed in their honor.

The Secretary read the names of the following applicants for Emeritus membership:

Joseph S. Ingraham, Indianapolis
James E. Newman, West Lafayette
Russell K. Stivers, West Lafayette
Dan Wiersma, Volga, South Dakota

They were named Emeritus Members.

The Secretary read a brief account of the meeting of the Council.

The Treasurer reported that the finances of the Academy are in good order.

William Gommel, Chair of the Committee on Fellows, nominated the following persons:

Konrad J. Banaszak, U.S. Geological Survey
David D. Chesak, St. Joseph's College
Ernest R. Davidson, Indiana University Bloomington
Vivie Dunn, Indiana State Board of Health
Eldon L. Hood, Purdue University
Gerald Zimmerman, University of Indianapolis

They were elected to the rank of Fellow of the Academy, and certificates were presented to those who were present.

William Davies, Chair of the Committee on Resolutions, presented three resolutions, all of which had been approved for presentation by the Council.

The first resolution thanked St. Mary's College, its administration and faculty, and especially program co-chairs David Sever and Richard Jensen, for extending their hospitality, facilities, and hours of planning to assure the success of the meeting.

The other two resolutions were developed by the Science Education Advisory Committee:

1. NEED FOR CHANGES IN EDUCATIONAL PROFICIENCY STATEMENTS AND ISTEP

WHEREAS subject matter of the sciences, such as factual content and concepts, is based upon skills for observation, experimentation, and thinking, and since both subject matter and skills are necessary to the sciences and science education, and

WHEREAS state education proficiency statements for science now indicate only the skills expected of a student, rather than skills *and knowledge base* as mandated by IC 20-10.1-16-1,

BE IT RESOLVED that the Indiana Academy of Science recommend to appropriate state officials that proficiency statements be established for a knowledge base of science, in addition to the proficiency statements for skills of science, and

WHEREAS ISTEP is to provide information on the *overall* academic progress of students (IC 20-10.1-16-5),

BE IT RESOLVED that the Indiana Academy of Science recommends to these state officials that the Indiana Statewide Testing for Educational Progress (ISTEP) include components which evaluate knowledge of subject matter in science separately from evaluation of science skills.

2. NEED FOR IMPROVED WORKING CONDITIONS FOR SECONDARY SCIENCE TEACHERS

WHEREAS quality of secondary science instruction is adversely affected when teachers have four or more different preparations per day, heavy student loads, large classes, or poor facilities; since laboratory classes can be hazardous when overcrowded or when there is inadequate supervision; and since it is inconvenient and distracting for all concerned when a teacher has to do lab preparations in a lab which is being used by another teacher and class,

BE IT RESOLVED that the Indiana Academy of Science recommends to appropriate state officials that accreditation standards be adjusted to provide optimal schedules, classrooms, and learning environments for science teachers to include, but not be restricted to the following:

A. A maximum of three different teaching preparations per day
B. A maximum of five science classes per day
C. A maximum of 24 students per class
D. Access to an adequately equipped laboratory at least two times per week for each class.
E. A preparation period in a teacher's own classroom without another teacher's class meeting concurrently

All three resolutions were approved.

Duvall Jones urged all present to attend the Symposium "Science Education at the Crossroads" to be held at the Lilly Auditorium on December 3.

The meeting was adjourned at 2:14 p.m.

Dr. Hayden H. Murray of the Department of Geology at Indiana University Bloomington and Speaker of the Year for 1989, spoke on "Industrial Minerals—A Critical Key to Economic Development." He dedicated the speech to the memory of John B. Patton.

Richard L. Conklin
Secretary

INDIANA ACADEMY OF SCIENCE MEETING OF THE EXECUTIVE COMMITTEE

December 10, 1988

The meeting was called to order by President Wilton Melhorn at 1:45 p.m. in the Auditorium of the Indiana State Library. Those present were Charlotte Boener, Standley Burden, Richard Conklin, James Haddock, Duvall Jones, Gene Kritsky, Scott Litherland, Wilton Melhorn, Holly Oster, Anne Rogers, and Donald Winslow.

Minutes of the meeting of November 10-11 were approved.

Saturday, February 25, 1989, was set as the date for a meeting of the Executive and Publications Committees with John Gallman of the Indiana Univerity Press. The location will probably be the State Library.

Anne Z. Rogers presented a detailed estimate of the costs of implementing the activities discussed at the Executive Committee meeting in November. After considerable discussion of principles and details, Burden moved that the Academy accept the proposal for items totaling $11,837. Her services are to begin as of March 1, 1989. The motion carried unanimously.

Burden distributed a draft of suggestions for the division of responsibilities among the Executive Liaison Officer (Winslow), the Public Relations Chair (Kritsky), and the Development Agent (Rogers). The version approved by the committee is appended to these minutes.

Membership of the Corporate Relations Committee was discussed. The consensus was that representatives of corporate members and of the other types of members should be on the committee. Perhaps this should be a designated responsibility of the Past President.

Winslow reported that a member wishes to have published in the *Proceedings* a paper which was not presented in any form at the Fall meeting. The Executive Committee reaffirmed the traditional position that in order to be published in the *Proceedings* a paper must have been presented at a meeting of the Academy.

The meeting was adjourned at 4:05 p.m.

Respectfully submitted,
Richard L. Conklin
Secretary

SUGGESTED DIVISION OF RESPONSIBILITIES BETWEEN EXECUTIVE LIAISON OFFICER, PUBLICITY DIRECTOR, AND DEVELOPMENT AGENT

Established by
Executive Committee of the Indiana Academy of Science
December 10, 1988

I. Executive Liaison Officer
  - A. Report to Executive Committee.
  - B. Serve as primary contact person to facilitate communication between various Academy officers and consultants in administering the day-to-day operations of the Academy business.
    - 1. Act as primary Academy contact with Development Agent
    - 2. Work closely with President in facilitating communication among Executive Committee, Development Agent and various Academy committees
  - C. Develop and Administer a Handbook of Operations for the Academy.
  - D. Coordinate Committee Chairs.
    - 1. Train new chairs
    - 2. Send information/reminders to all chairs
    - 3. Keep records on performance of all chairs and, to the extent possible, the committee members
    - 4. Develop and keep updated a list of new or additional persons willing and able to serve on committees
    - 5. Assist President in selection of committee chairs and committee members for following year based on the above records
  - E. Coordinate (work closely with appropirate chairs) in the publishing of the *Proceedings,* Abstract Booklet, Announcements of Fall and Spring meetings and Symposia.
    - 1. Work closely with the Editors and Program Chairs
    - 2. Advise, assist and provide backup where necessary to insure timely and accurate publications
  - F. Develop and maintain contacts with state agencies which will lead to increased cooperative efforts.
    - 1. Indiana State Museum
    - 2. Children's Museum
    - 3. Etc.
  - G. Coordinate interactions with other science and education groups.
    - 1. AAAS, SEFI, etc.
  - H. Coordinate, stimulate and assist in grant writing as directed by the Executive Committee.
  - I. Serve as Ex Officio member of all committees (without vote).
  - J. Chair the *ad hoc* Corporate Relations committee.

II. Public Relations Director/*Newsletter* Editor
  A. Publish and distribute *Newsletter.*
  B. Coordinate, stimulate and assist in writing and evaluating press releases and media relations.
    1. Meet with Development Agent and establish policies and target groups for media relations
      a. Do this at Fall meeting and work out policy and schedule for entire year
      b. Submit to the Executive Committee for approval
  C. Arrange and co-ordinate IAS exhibits and publicity at national science meetings.

III. Development Agent
  A. Science Notes.
    1. Sent to media
    2. Follow-up telephone conversations would generate information regarding where stories would appear and a report of where articles appear will be furnished to the Executive Committee
  B. Youth Programs Publicity.
  C. Communiques to Governor, State Superintendent of Schools and Key Legislators.
  D. Corporate Contacts Regarding Youth Programs.
  E. Corporate Solicitation.
  F. New Member Recruitment Drive.
  G. Peer Recruitment Drive.
  H. Central Office Telephone and communication facilitation in close contact with Executive Liaison Officer.

INDIANA ACADEMY OF SCIENCE
MEETING OF THE BUDGET COMMITTEE

December 10, 1988

The meeting was called to order by President-elect Charlotte Boener at 9:00 a.m. in the Auditorium of the Indiana State Library.

Members present and their office or committee were Charlotte Boener (President-elect., Austin Brooks (Research Grants), Marshall Cady (Program), Richard Conklin (Secretary), Frank Guthrie (Academy Foundation), James Haddock (Secretary-elect), Duvall Jones (Treasurer), Gene Kritsky (Public Relations), Wilton Melhorn (President), Holly Oster (Library), Mark Whitman (Junior Academy), and Donald Winslow (Editor).

Treasurer Duvall Jones distributed the proposed budget.

There was considerable discussion of the sending of a delegate to the annual meeting of the AAAS. Whitman pointed out that the Junior Academy sends a high school teacher and a student, but they have not been asked to report on the meeting. After considering sending two delegates to the meeting, the committee decided to send one delegate to Section Y, and to budget $850 for expenses. Gene Kritsky will be that delegate in 1989.

Cady reported that the printing office at Indiana University Southeast has estimated the cost of printing the abstract/program booklet for the Fall meeting to be $3.10 per copy, a total of $4,960 for 1600 copies. After some consideraiton of returning to a program without abstracts, the committee decided to retain the format used in recent years. $2700 was budgeted for printing the spring and fall programs. Sending the fall program by second-class mail was recommended.

An increase of $575 in the allocation for the Junior Academy was approved.

A request by the Biological Survey Committee for $500 to prepare a directory of systematic biologists was denied.

At Kritsky's suggestion the allocation of $1800 for the *Newsletter* and $500 for Public Relations were combined under the *Newsletter* line item.

Whitman moved that a total of $22,000 be allocated to Development and Liaison. The motion carried.

The Indiana Science Talent Search was allocated $1000 and added to the Program Service group of line items.

Jones moved that the budget be approved as modified. The motion carried. A copy of the budget is attached to these minutes.

Upon motion by Jones the registration fees for the Fall meeting were set at $5.00 for members and $7.00 for non-members.

Jones moved that in the 1988 buget $60 be transferred from the *Newsletter* to telephone expenses and $200 to Development. The transfers were approved.

The meeting was adjourned at 1:00 p.m.

Respectfully submitted,
Richard L. Conklin
Secretary

INDIANA ACADEMY OF SCIENCE

Financial Report

1 January-31 December 1988

I. Operating Funds

	Receipts	Budgeted	Expenses	Budgeted
A. Income				
Dues	$16,700.00	$15,500.00		
Contributions	211.00	300.00		
Interest	3,276.65	2,300.00		
Reserve Funds		5,700.00		
B. Management Expenses				
Academy Development	111.50		$1,725.82	$1,850.00
CPA Fees			550.00	550.00
Fees and Insurance			294.80	500.00
Membership Services			50.00	200.00
Office Services			891.23	1,100.00
Office Supplies			470.90	650.00
Postage and Shipping			1,134.34	1,150.00
Telephone			91.00	110.00
Travel			340.00	350.00
Subotal			$5,548.09	$6,460.00
C. Program Services				
AAAS Representative			$ 500.00	$ 500.00
Biological Survey			100.00	100.00
Editorial Board Awards			150.00	300.00
Newsletter			360.75	1,540.00
Public Relations			500.00	500.00
Science and Society Committee	2,824.00		3,295.59	1,600.00
Science Education Advis. Com.			142.92	200.00
Science Olympiad			386.81	400.00
Speaker of the Year			3,000.00	3,000.00
Subtotal			$9,136.07	$8,840.00
Transferable to Dedicated Accounts				
Junior Academy	(2,000.00)			$2,000.00
Library Binding	(1,600.00)			1,600.00
Print Programs & Abstracts	(2,000.00)			2,000.00
Publications: Mailing	(700.00)			700.00
Reprints				2,200.00
Totals	$16,823.15	$23,800.00	$14,684.16	$23,800.00

II. Dedicated Funds

	1 January Balance	1988 Transfers and Income*	1988 Transfers & Expenditures	31 December Balance
Junior Academy of Science	$ 819.45	$ 2,000.00(T_1)	$ 3,668.60	$ 150.85
Grant from IBM		1,000.00(I)		
Lilly Library Fund	7,007.64	0.00	69.47	6,938.17
Library Binding	3,369.50	1,600.00(T_1)	0.00	4,969.50
Meetings and Programs	1,620.34		828.15	
Transfer from Program & Abstracts		2,000.00(T_1)	3,008.66	
Registration Fees		1,308.32(I)	1,033.78	
Meals		1,264.29(I)	1,322.36	
Publications: Mailing	882.57	700.00(T_1)	1,281.43	0.00
Publications: Printing	1,952.89	7,841.16(T_1)	9,794.05	0.00
Grant from State of Indiana		8,900.00(I)		
Direct transfer to printer		(8,900.00)		
Publications: Sales	8,781.46	51,504.71(I)	45,410.75	14,875.42
Reprints: Volume 96	677.69	2,420.25(I)	2,726.98	370.96
Research Fellows	149.25	2,500.00(T_2)	2,500.00	149.25
Research Grants: High School	300.00	500.00(T_2)	1,928.00	576.00
Grant from AAAS		1,200.00(I)		
Contribution and Funds returned		10.00(I)	(494.00)	
Research Grants: Senior	658.56	33,460.00(T_2)	33,610.00	623.97
Funds returned			(115.41)	
Science Talent Search	2,454.53	84.00(I)	2,527.41	2,511.12
Grant from Kappa, Kappa, Kappa		2,500.00(I)		
Totals	$28,673.88	$111,892.73	$108,272.08	$32,294.53

*I: Income from external sources
T_1: Transfer from Operating Accounts
T_2: Transfer from Academy Trust funds

III. Summary

	Operating Accounts	Dedicated Accounts	Totals
Balance: 1 January 1988	$14,612.73	$ 28,673.88	$ 43,286.61
1988 Income	16,823.15	111,892.73	128,715.88
1988 Expenditures	14,684.16	108,272.08	122,956.24
Balance: 31 December 1988	$16,751.72	$32,294.53	$49,046.25

IV. Bank Balances (as of 31 December 1988)

Bank One, Rensselaer, IN: Money Market Checking Acct #21-0497-4	$ 9,448.03
Money Market Savings Account #70-0325-4	12,337.35
CD #11985	3,542.30
Bank One, Lafayette, IN: CD #94001654185	5,000.00
First of America Bank of Rensselaer, IN, CD #100212712	9,266.64
Indiana Federal S&L, Rensselaer, IN: CD #10620000140111	3,879.75
Lafayette National Bank, Remington, IN: CD #370-02531-8	2,750.08
CD #302641	2,822.10
Total	$49,046.25

V. Foundation Funds

	Research Account (430-00-0)	J.S. Wright Fund (430-02-8)	Invested Income (430-02-8)	1988 Budgeted Expenses
A. Assets (1 January 1988)				
Cash	$ 14.14	$ (4,755.96)	$ 4,980.88	
Tax Value of Investments	53,054.95	562,612.43	135,759.55	
Tax Value of Account	53,069.09	557,856.47	140,740.43	
B. Income and Transfers				
Dividends	606.00	29,275.50		
Interest	2,639.86	25,277.15	9,305.81	
Transferred from Invested Income		1,865.66		
Sales of Investments (net)		(1,283.12)	213.20	
Transfer from J. S. Wright Fund			52,675.18	
C. Expenditures and Transfers				
Fiduciary Fees	(16.18)	(6,602.51)	(77.93)	(7,000.00)
Distributions to Programs				
Research Grants—High School	(300.00)		(200.00)	(1,400.00)
Research Grants—Senior			(33,460.00)	(35,000.00)
Summer Research Fellow			(2,500.00)	(5,000.00)
Print *Proceedings*—Volume 96			(7,841.16)	(10,500.00)
Print *Butterflies of Indiana*			(35,000.00)	(35,000.00)
Print Endangered Species			(3,988.00)	(8,000.00)
Flora of Indiana				(8,000.00)
Program and Abstract Booklet (1988)				(1,500.00)
Climate of Indiana				(15,000.00)
Executive Liaison Officer				(11,000.00)
Transfer from Dedicated Funds				4,000.00
Transfer to Invested Income		(52,675.18)		
Transfer to J. S. Wright Fund			(1,865.66)	
Balance—30 December 1988	55,998.77	553,713.97	118,001.87	
D. Assets—30 December 1988				
Cash	43.82	53.91	6,339.37	
Tax Value of Investments				
Short Term Investments	10,300.00	61,900.00	71,700.00	
Bonds	25,742.19	300,864.96	39,962.50	
Stocks	19,912.76	190,895.10		
Tax Value of Accounts—30 December	55,998.77	553,713.97	118,001.87	
Market Value of Principal—30 December	55,146.82	1,346,548.16		
E. Summary				
Total Assets of Foundation—1 January 1988		751,665.99		
Total Income—1988		66,034.40		
Total Expenditures—1988		89,985.78		
Total Assets of Foundation—30 December 1988		727,714.61		

VI. Notes

A. Membership. There were 1220 memberships for 1988 as of 31 January 1989

3 honorary members
5 corporate members
(including 14 persons)
4 life members
105 emeritus members
89 sustaining members
687 members
152 associate members
113 student members
62 clubs

9 members deceased in 1988 are not included in the total above
231 memberships on file from 1987 were not paid for in 1988
187 new and reinstated members joined the Academy in 1988
152 members and clubs were dropped for nonpayment of 1986 dues
180 members and clubs were dropped for nonpayment of 1987 dues

B. Dues structure for 1988:

$ 5	for clubs and student memberships
10	for associate memberships
15	for members
25	for sustaining members
300	for life memberships
150-500	for corporate memberships
50-100	for institutional memberships

C. Reprints. All authors of papers in Volume 96 of the *Proceedings* have paid for reprints which they ordered. Cost of the reprints to the Academy was $2,726.98. Authors paid the Academy $3,046.75 for reprints.

D. Publications. Sales of reprints, monographs, *Proceedings,* and other publications netted $5,787.23 in 1988. Sales of the *Butterflies* of Indiana are shown below.
1987 Regular sales: 759 copies with royalty of $6,445.10
1987 Special sales: 1,121 copies with royalties of $750.00
1988 Regular sales: 528 copies with royalties of $4,569.52
1988 Special sales: 11 copies with royalties of $443.72

E. Research Grants. Funds totaling $37,428.59 have been awarded to members and students.

F. Grants Received. The State of Indiana contributed $8,900.00 toward publication of the Academy *Proceedings*. The Science Talent Search received $2,500 from Kappa, Kappa, Kappa Sorority, and the American Association for the Advancement of Science granted $1,200 for high school students to use in their research.

G. Meeting Income and Costs.
Income in addition to dues: $2,723.41. (Registration fees, $1,308.32; meals, $1,264.29)
Expenses—Spring Meeting: $179.97. (Print program, $121.90; meal expenses, $58.07)
Fall Meeting: $3,885.29. (Print forms and abstract booklet; $975.51, mailings (2), $1876; refreshments and Av equipment, $1,033.78)

H. Science Education Symposium. 180 persons.
Registration fees and contributions: $2,824.00
Expenses: $3,156.81

VII. INDIANA ACADEMY OF SCIENCE BUDGET 1989

1.	Operating Accounts—Receipts		
	Dues		$ 17,500
	Contributions		300
	Interest		3,000
	Transfer from Foundation Fund		20,213
	Reserve funds (budgetary deficit)		8,725
	Total		$ 49,738
2.	Operating Accounts—Disbursements		
	Management Expenses		
	Executive Liaison Officer		9,000
	Academy Development		2,000
	CPA fees		550
	Equipment repair		500
	Fees and insurance		400
	Office services		1,150
	Office supplies		850
	Postage and shipping		1,400
	Telephone		150
	Travel		600
		Subtotal	$ 16,600
	Program services		
	AAAS representative		850
	Biological Survey		1,050
	Editorial Board Awards		300
	Public Relations Consultant		11,213
	Newsletter		2,300
	Science and Society Committee		1,600
	Science Education Advisory Comm.		500
	Science Olympiad		500
	Speaker of the Year		700
	Youth Activities Committee		3,150
		Subtotal	$ 22,163
	Transferable to Dedicated Accounts		
	Abstract booklet and programs		2,700
	Junior Academy		2,575
	Library binding		1,600
	Publications: Mailing		800
	Reprints		2,200
	Lilly Library Fund		100
	Science Talent Search		1,000
		Subtotal	$ 10,975
		Total	$ 49,738
3.	Trust Funds		
	Anticipated Income and Expendable Funds (30 September 1988)		
	Research Fund	(00430-00-0)	$ 3,400
	John S. Wright Fund	(00430-01-9)	55,000
	Invested Income Account	(00430-02-8)	131,000
	Approved Expenditures		
	Fiduciary fees		$ 7,000
	Research grants for Senior Academy members		37,000
	Research fellowships for high school teachers		5,000
	Research grants for high school students		1,400
	Expenses of Research Grants Committee		200
	Executive Liaison Officer		9,000
	Publications		
	Program and Abstract booklet		1,500
	Proceedings (Volume 97)		11,000
	Climate of Indiana		15,000
	Flora of Indiana		8,000
	Symposium booklet		2,500
	Public Relations Consultant		11,213
		Total	$108,813

Necrology

Fay Kenoyer Daily, Butler University

A(RCHIE) LEE CALDWELL

Doniphan, Missouri	Carmel, Indiana
October 10, 1901	September 2, 1988

Mr. A. Lee Caldwell, born October 10, 1901, at Doniphan, Missouri, grew up in the rural atmosphere of the area and graduated from West Plains Missouri High School. He attended the Philadelphia College of Pharmacy and Science receiving a Ph.G. degree in Pharmacy in 1921 and a Ph.C. degree in Chemistry in 1922.

From 1923 to 1925, he was an instructor of Chemistry in the Philadelphia College of Pharmacy and Science. In 1925, he joined the staff at Eli Lilly and Company at Indianapolis, Indiana, where he worked in the pharmaceutical research and development department until 1937. Dr. Caldwell's research interests included studies on barbituric acid compounds, antioxidants in pharmacy, oil soluble vitamins, and liver protein purification for nutritional use. He had a son, Dr. Archie Lee Caldwell, Jr. in 1931, who also became a research scientist in pharmacy.

From 1937 to 1950, Dr. Caldwell, Sr. was head of the nutrition and vitamin research department at Lilly. He developed *Homocebrin* liquid vitamin for children and was a patentee. In 1950, he was made head of the product technical service in which capacity he served untill 1966 when he retired from the company after 41 years of association.

Beginning in 1966, A. Lee Caldwell joined the Fletcher Avenue Savings and Loan Association (now Security Savings and Loan) in Indianapolis as vice-president. He was also named as director in 1952. In other capacities, he served as vice-president of the Nor-Brook Civic League in 1947 and was Trustee of the Philadelphia College of Pharmacy and Science.

Mr. Caldwell joined the Indiana Academy of Science in 1947 and was interested in the Chemistry Section. He was also a Fellow of the American Institute of Chemists, member of the American Chemical Society, American Pharmaceutical Association, New York Academy of Science, Upsilon Sigma Phi, Scottish Rite and other clubs and fraternities.

Mr. Caldwell was the subject of articles in the "Indianapolis Star" and "Savings and Loan League of Indiana Ledger." He was also a biographee in *Who's Who in the Midwest* and Visher's *Indiana Scientists.* Much of the material here was found in these publications.

Mr. Caldwell was a gracious, likable man and much respected by his coworkers. He died September 2, 1988, at which time he resided in Carmel, Indiana.

FELIX (MICHAEL) HAUROWITZ

Prague, Czechoslovakia	Bloomington, Indiana
March 1, 1896	December 2, 1987

Dr. Felix Haurowitz was a distinguished professor of Chemistry at Indiana University, Bloomington, Indiana, a long way from his birthplace when he died December 2, 1987, in Bloomington. He was born in Prague, Czechoslovakia, March 1, 1896, into a prominent family interested in literature and foreign language. He learned French, English, Czechoslovakian, and German and became interested in physics, mathematics, and chemistry. He was drafted into the Austrian army in 1915 and attended an officers' artillery school. He was granted a leave to attend the German University in Prague where he received a D.Sc. degree in 1923. He was made Assistant Professor of Physiological Chemistry in the Medical school in 1925 and was associate professor by 1930. He became famous for his work in hemoglobin here and traveled to conferences in the U.S. and Europe. He began a series of books in German on progress in Biochemistry bringing much recognition. He felt that his greatest accomplishment was the part he played in the development of biochemistry in German-speaking countries.

Then came the Nazi invasion and Dr. Haurowitz was forced to flee his native land in 1939. He accepted an invitation to join the Department of Biological and Medical Chemistry at the Medical School of the Unviersity of Istanbul, Turkey, where he taught until 1948. He soon learned the Turkish language and was able to teach in the students' native tongue.

When the Haurowitz family left Turkey in 1948, their daughter was accepted at Indiana University at Bloomington and came to live in the home of Professor and Mrs. Harry Day while attending the university. This led to Dr. Day inviting Dr. Haurowitz to lecture at the university. Soon after that, Dr. Haurowitz was asked to accept a teaching assignment in the Chemistry Department which he did that year. He not only was well-known for his work on hemoglobin but also his pioneering work on antibody biosynthesis advancing the template theory. A review on antibody production resulted in his receiving around 2000 reprint requests from many parts of the world. He was a dedicated teacher and well-liked by students and faculty. He retired from teaching in 1966 at which time he was made an honorary member of Phi Beta Kappa. His son and daughter also have pursued scientific careers.

Many honors were bestowed on Dr. Haurowitz through the years. He received the Ehrlich medal in Germany in 1960, election to the Leopoldina Academy of East and West Germany, U.S. National Academy of Sciences, American Academy of Arts and Sciences, honorary memberhip in several American and foreign societies, an honorary M.D. by the University of Istanbul, and honorary Sc.D. from Indiana University in 1974. He was especially honored by the Haurowitz symposium at Indiana University in 1973 at his 77th birthday which drew several hundred immunologists from around the world. His publications numbered about 300 papers and 9 books written in three languages: German, Turkish and English.

Dr. Haurowitz joined the Indiana Academy of Science in 1949 and was made a Fellow in 1958. He spoke before the Chemistry Division at the 1955 fall meeting on condensation of proteins with thiocyanate.

Besides the Indiana Academy of Science, Dr. Haurowitz had many other affiliations here and abroad. Among them were: the Board of Editors for the *Proceedings for Experimental Biology and Medicine;* Fellow, American Association for the Advancement of Science; International Society of Hematology; American Society of Biological Chemists; American Association of Immunologists; American Society of Naturalists; Biochemical Society (London); Society of Chemical Biology (Paris); and German Society for Physiological Chemistry (Frankfurt).

Dr. Haurowitz had many talents other than scientific and language abilities. He could play the piano well and was an entertaining and gracious host. He was interested in mountaineering in his youth.

Dr. Haurowitz died in Bloomington, Indiana, after an extraordinary long life of accomplishment. We are indebted to a fine memorial from Indiana University for much of this material. The memorial was prepared by Frank W. Putnam, John P. Richardson, Frank R. N. Gurd, and Harry G. Day.

DONALD C. HAZLETT

Russellville, Indiana
August 20, 1905

Russellville, Indiana
December 13, 1987

Mr. Donald C. Hazlett, native of Russellville, Indiana, was born August 20, 1905. He was a geologist, explorer, teacher, and naturalist. His early education was at Russellville and higher education at the University of Illinois, Urbana, where he earned a B.S. degree in 1928. Some graduate work was taken at Oberlin College, Ohio, where he was an assistant in the Department of Geography and Geology.

His professional experience began with employment by the Westinghouse Electric Company, Pittsburgh, Pennsylvania, where he worked two years. He was then a geologist with the National Park Service for eighteen years. After that, he was a high school teacher at Catlin, Illinois; West Point, Bainbridge, and Roachdale, Indiana, retiring in 1972.

Mr. Hazlett had some very unusual and exciting experiences in his lifetime. He had an encounter with a grizzly bear, found water for troops in the Virgin Islands during World War II and found some unique fossils now lodged at the Smithsonian Institution. With the National Park Service, he explored Mammoth Cave mapping heretofore unseen areas and setting foot on portions never seen by man before. He took a picture of the footprints of the surveying team in the cave where no other footprints were visible. He was also concerned with conserving natural resources, studied concretions in Ohio shale and beach erosion of the Outer Banks of North Carolina. He wrote many articles on nature for state parks in several states and was an accomplished nature photographer.

Mr. Hazlett joined the Indiana Academy of Science in 1930 and was a member 57 years. He listed as interests the Botany, Entomology, and Zoology Sections. He was also a member of the Indiana Society of Retired Teachers, Masonic Lodge, Eastern Star, and International Wood Collectors Society. He could turn both wood and stone into beautiful works of art.

Mr. Donald C. Hazlett was much admired as a respected teacher and geologist. He died at his home in Russellville December 13, 1987.

ROBERT L. KENT

Shelbyville, Indiana
August 19, 1916

Indianapolis, Indiana
January 14, 1988

Dr. Robert L. Kent was professor emeritus of Biology at Indiana Central College (now the University Indianapolis) where he taught for 34 years (from 1946 to 1980). A scholarship fund has been established there in his honor. He joined the biology faculty while Dr. William P. Morgan was still there.

Dr. Kent was born in Shelbyville, Indiana, on August 19,1916. His college education began at Butler University of Indianapolis, Indiana, where he majored in Botany and was interested in microbiology. Through the years he had various occupations as an adjunct to his teaching and continuing education. He cleared land on his farm near Martinsville, farmed, was connected with the distribution of chemical fertilizers, developed an interest in environmental quality, food technology and education. After graduation from Butler University, he took graduate work at Indiana University and then received an Ed.D. degree at Ball State University. His perseverance in pursuit of a degree along with the complex of activities in which he engaged was admirable. He married Charlene Gudgel, also a Botany major at Butler University. He served in the Coast Guard in World War II.

Dr. Kent joined the Indiana Academy of Science in 1938 and served on various committees. He was a member of the Membership Committee many years and served as chairman in 1958 and was on the Executive Committee (now Council). He was a member of a special committee on Undergraduate Research in Biology, Youth Activities and was Chairman of the Botany Section and on the Executive Committee in 1969. He gave a paper at an annual meeting before the Bacteriology Section in 1947 on "Antibiotic Behavior Patterns of Living Cultures of *Pseudomonas.*"

Other affiliations also kept Dr. Kent busy such as: Research Group Incorporated (president); Environmental Group, Incorporated (president); Environmental Education Association; American Association for the Advancement of Science; Indiana Food Technologists; Indiana Chapter of the National Education Association; Smithsonian Institute; and National Historical Society.

Dr. Robert L. Kent was 71 years old when he died of cancer at the Indiana University Hospital in Indianapolis, Indiana, on January 14, 1988.

ALFRED H(ERMAN) L(UDWIG) MEYER

Venedy, Illinois
February 27, 1893

Valparaiso, Indiana
February 27, 1988

Dr. Alfred H. Meyer (Figure 1) was teacher, scholar, university administrator and civic-minded citizen. He was born in Venedy, Illinois, February 27, 1893, theyoungest of 8 children. Dr. Meyer was educated in the Venedy Saint Salvator Lutheran one-room school from 1900 to 1910 when he completed the 9th grade. He attended Southern Illinois Normal (Carbondale) in the summers of 1911 and 1912; Eastern Illinois Normal (Charleston) during the summer of 1913; and then McKendree College (Academy), Lebanon, Illinois, 1914 to 1916, to complete secondary school training. He began his higher education at McKendree College in 1916 but changed to the University of Illinois after a year where he earned an A.B. degree in Geology in 1923 and an A.M. degree in Geology in 1927. The teachings of geologists with a negative attitude toward the biblical account of creation conflicted with his convictions so he changed to an accent on geography instead of so much geological training. He studied at Northwestern University and the University of Chicago and finally the University of Michigan where he received a Ph.D. degree in Geography in 1934. His doctoral dissertation was on "The Kankakee Marsh of Northern Indiana and Illinois."

His professional career began south of Venedy, Illinois, in a one-room school house from 1911 to 1914. From 1925 to 1926 he taught at a second school, the Englewood Institute, located at the south side of Chicago. He came to Indiana to teach at Valparaiso University in 1926 as an instructor in Geology and Zoology. In 1931 he became an associate professor and head of the Department of Geography and Geology. He had advanced to the rank of Professor in 1942. In 1967, he resigned as head of the department and retired in 1973. Not only was he founder and leader of a modern Department of Geography and Geology, he planned the Graduate Division and was considered one of the founding fathers of the university itself. He was named Valparaiso University Distinguished Service Professor of Geography in 1968.

He was co-author of an introductory college textbook on geography with John H. Strietelmeier called *Geography in a World Society—A Conceptual Approach*. He collaborated on "Valparaiso Master Planning—a Guide for Future Community Development" when he was President of the Valparaiso City Planning Commission. He published many other articles many of which appeared in a *Proceedings of the Indiana Academy of Science*. He became a member of the society in 1926, the year he started teaching at Valparaiso University, and he was honored as a Fellow in 1945. His studies were largely on manufactural geography and city planning in the northwest corner of Indiana often in conjunction with other authors especially in later works. Studies covered in Indiana: LaPorte, Michigan City, the Calumet area, Chicago Heights, Gary, East Chicago-Whiting, and Hammond. Blue Island, Illinois, was also among the studies reported at meetings of the Academy. Dr. Meyer became President of Indiana Academy of Science in 1955.

Dr. Meyer had visited Europe and Israel, and was engaged in various other organizations than those already mentioned. He belonged to the Association of American Geographers (past president and program chairman). He was elected Fellow of the American Association for the Advancement of Science, president of

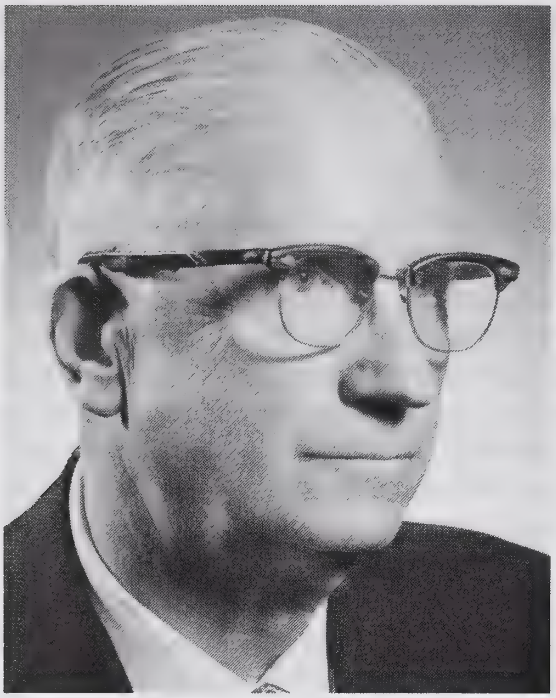

FIGURE 1. Dr. Alfred H. Meyer

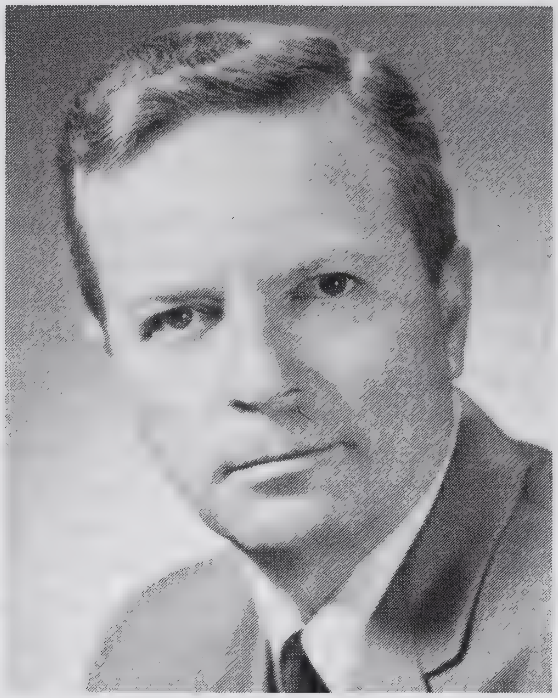

FIGURE 2. Dr. John Barratt Patton

the Indiana Academy of Social Science, chairman and past-president of the Valparaiso City Planning Commission and served in the United States Army in World War I and was in the Special Officers Training Company, Camp Hancock, Augusta, Georgia. In 1986, the National Council for Geographic Education honored him at their annual convention in Chicago. He was a former president (1947) and distinguished service award recipient (1969) from that organization. He was coordinator for the National Council for Geographic Education for Indiana 1961 to 1965 and National Defense Education Act evaluator of geography teacher institutes for the Midwest in 1965. He was also Director of the Chicago Regional Planning Association and received an Honorary Alumni Membership award from the Valparaiso University Alumni Association given because of his "personal and professional activities which reflect the highest ideals for which the University stands."

Dr. Alfred H. Meyer died at Valparaiso, Indiana, February 27, 1988, on his birthday. He had lived a long and distinguished life.

JOHN BARRATT PATTON

Marion, Indiana	Bloomington, Indiana
July 1, 1915	September 16, 1988

Dr. John Barratt Patton (Figure 2) was a geologist, educator, consultant in his field, civic-minded man and family man. His dependability, strength and good judgement were quite evident.

Dr. Patton was born in Marion, Indiana, July 1, 1915. He attended high school in Anderson where his leadership qualities were recognized at an early age. He was elected president of his graduating class. His higher education at Indiana University resulted in an A.B. degree with honors in 1938 after majoring in chemistry. He had also developed an interest in geology in which he majored to receive an A.M. degree in 1940 and a Ph.D. degree in 1954.

After obtaining his master's degree, Dr. Patton accepted a position as geologist in exploration and development for the Magnolia Petroleum Company now with the Mobil Oil Corporation.

In 1947, Dr. Patton came back to Indiana to complete his education at Indiana University and join the Indiana Geological Survey. During this period, his special interests were in stratigraphy and the economic geology of fuels and industrial minerals. Through the years his work was often the subject of news articles in Indianapolis newspapers. When he was planning retirement in 1986, Dan Carpenter of the *Indianapolis Star* ran a column (May 11, 1986) selecting highlights of his career. Dr. Patton's studies on the potential for oil in the Albany Shale and his improvement in mapping our mineral resources were cited as probably his most important contributions to the state. His rank at Indiana University rose rapidly reaching full professorship in 1955. He was made Director of the Geological Survey and also Chairman of the Indiana University Geology Department in 1959. He also served two years in the Office of Research and Graduate Development as associate dean. He retired in 1986 teaching his last course in economic geology that May. However, he kept an office at the unviersity to complete some work.

It seemed very remarkable that he could manage so many assignments at one time and yet do all of them so well. It speaks well for his management ability as well as the ability of his able staff. He served with the National Research Council, North American Commission on Strategic Nomenclature, Interstate Oil Compact Commission, Indiana Energy Development Board, American Association of Petroleum Geologists and Bloomington Environmental Quality and Conservation Commission.

Dr. Patton developed a special interest in building stone regarding its geological and geographical location, quarrying, quality, and maintenance. This resulted in much travel connected with restoration and preservation projects such as the Alamo in San Antonio, Texas, Christ Church in Indianapolis, and many other government and private buildings. He received a special citation for his activity in this field at a conference on historic preservation at Indiana University in 1986. This was one of many honors bestowed on him. Just 20 years previously in 1966, the American Association of Petroleum Geologists presented him with a Service Award. He also received the Centennial of Service Award from the University of Notre Dame recognizing his research contributions to the state. He was elected Distinguished Member of the Society of Mining Engineers, made a Sagamore of the Wabash, and inducted into the Indiana Academy.

In a news release from Indiana University, Dr. Patton's part in modernizing the Geological Survey (Division of the Indiana Department of Natural Sciences) is discussed. Much of the Survey's environmental geology activity developed while he was there. Work done before on land use, planned reclamation, and waste disposal was now applied to the relationship between man and the earth. One of the first courses in the United States of America on urban and environmental geology was established at Indiana University in the 1960's. Consulting firms and government agencies are interested in the subject.

Dr. John B. Patton joined the Indiana Academy of Science in 1947, the year he came to Indiana to join the Geological Survey team and was honored as Fellow in 1961. He was elected president in1975. His address, "Such Quantities of Sand," was quite interesting. In it, he discussed sand with relation to its uses, as a barrier, and as a source of recreation. He also considered its political, geographic and protective aspects. Dr. Patton served on many important committees through the years including his active participation in the Executive Committee (now Council). He was on the Membership, Research Grants, Science and Society, Relationship of the Academy to State, Budget, and Speaker of the Year Selection (often Chairman) Committees. He was Chairman of the Special Committee for our Centennial Program and as such wrote an introduction to a history of the society written for the centennial celebration. He was co-author of a paper with F. E. Kottlowski as early as 1952 on "Pre Cambrian Rocks Encountered in Test Holes in Indiana" given at an Academy meeting and was author or co-author of many other papers given at the History of Science or Geography and Geology Sections.

Dr. Patton contributed much to the Indiana Academy of Science also by organizing and participating in several symposia, and by a special address. At the Hanover College dinner meeting of the Academy in April, 1969, he gave a special address, "To Ruine a World," with text and title from Fontenelle's *Plurality of Worlds*. He gave an environmental view of the world from a geologist's standpoint. On October 26, 1973, at a general session meeting of the Academy held at Indiana Central College (now the University of Indianapolis), he participated in a symposium sponsored by the Historical Section and moderated by John J. Favinger on the history of the Indiana Department of Natural Resources. Robert Hollingsworth, Burt Hamrick, Louis Hasenstab, Robert Jackson, and W. B. Barnes were also panelists. The next year, 1974, at Greencastle, Indiana, on November 11, Dr. Patton coordinated a panel discussion at the General Session meeting on "Search for Better Ways to Utilize Scientific Advisory Resources in Indiana." Panelists were: Captain R. L. McArthy (from the governor's science advisory committee), Dr. Harry G. Day (from Indiana University), Dr. Robert Henderson (from Indianapolis Center for Advanced Research), and Senator Patrick Carroll (from the Indiana State Senate). In 1977, Dr. Patton was Speaker of the Year and lectured before the Academy October 28 at the Indiana University-Purdue University Indianapolis campus. The title was "The Invisible Crisis: Implications for Indiana of the Federal Energy Policy." He organized a group of panelists to respond. They were Dr. Robert Henderson, Indianapolis Center for Advanced Research; Dr. Ralph Llewellyn, Indiana State University; and Dr. Philip Powers, Purdue University. Again in 1979, Dr. Patton was on a panel of another symposium chaired by Dr. William Beranek, Jr. on October 14 at Manchester College, North Manchester. The subject was "Science and Public Policy in Indiana." Other panelists were Mr. William J. Andrews, Deputy Director of the Indiana Department of Natural Resources; Mr. William Watt, Executive Assistant to the governor; Dr. Joseph Hartley, Department of Transportation, Indiana University School of Business.

Dr. Patton also had served as president of the Association of American State Geologists and Indiana University Chapters of Phi Beta Kappa and the American Association of University Professors. He was also a member of Sigma Xi, Geological Society of America, Society of Economic Paleontologists and Mineralogists, Indiana-Kentucky Geological Society, Society of Economic Geologists, and the American Association for the Advancement of Science.

Dr. John Barrett Patton died September 16, 1988, after a two year gallant fight against cancer. During his last illness, he was still able to function well on some Academy Committees to which he had been appointed. During that time, he made an important contribution to the history of the State Geological Survey in an article published in Department of Natural Resources Special Report 44, 1987, written to commemorate the sesquicentennial. He was a kind and remarkable man.

CHARLES PRESTON WARREN

Chicago, Illinois
April 7, 1921

Chicago, Illinois
December 22, 1987

Mr. Charles Preston Warren was an associate professor of Anthropology at the University of Illinois of Chicago when he died December 22, 1987. He was born in Chicago, April 7, 1921.

During undergraduate education at Northwestern University, he became interested in Anthropology. He received a B.S. degree in Zoology from that university in 1947, where he had been the first black quarterback on a Big Ten team. His formal education was put aside during World War II when he served in the Far Eastern with the Army Air Corps. There, he had the opportunity to study Far Eastern culture.

Mr. Warren's education continued at Indiana University where he studied physical anthropology and African folklore earning an M.A. degree. In 1950 to 1951, he returned to the Philippines for study as a Fulbright Scholar at the University of the Philippines. He became a physical anthropologist stationed with the U.S. Army American Graves Registration Service from 1951 to 1955.

Mr. Warren returned to the United States of America in 1957 to teach on the Navy Pier campus of the University of Illinois. He was one of the University's first black members. He also joined a Philippine Studies Program at the University of Chicago Anthropology Department. He was research associate and received a second M.A. degree in 1961.

A new campus for the University of Illinois at Chicago was available in 1965 when Mr. Warren moved to that campus. Thus, he had the longest tenure of the anthropology faculty on that campus. He specialized in ethnography of Southeast Asia and Forensic Anthropology.

In 1973 to 1975, on sabbatical leave, Mr. Warren served the Army again as Forensic Anthropologist in the Central Identification Laboratory in Thailand. He received the Army's Meritorious Civilian Service Award for his work.

Mr. Warren joined the Indiana Academy of Science in 1949 with an interest given as the Anthropology Section. He was very active giving several papers and was elected Chairman of the Anthropology Division in 1979 and 1981. As such he was also on the Executive Committee (now Council). He was also active in other organizations and served as president of the Central States Anthropological Society and *ex officio* member of the Executive Board of the American Anthropological Association. In 1987, the Association of Black Anthropologists of the American Anthropological Association gave him a Distinguished Service Award. His publications had a wide range of topics from folk tales and culture in Central Africa to Philippine ethnography and forensic problems.

Mr. Warren was not only a scholar, but also very personable. The news release from the University of Illinois at Chicago to which we are indebted for much of this information was a fine testimony for his achievements. He died December 22, 1987, of leukemia. A Warren Memorial Library Fund has been established at the University of Illlinois at Chicago with contributions to be received by the Department of Anthropology.

GRANT TOWNSEND WICKWIRE

Berlin, Connecticut Eastford, Connecticut
August 26, 1896 1986

Professor Emeritus Grant T. Wickwire was a patriot and a geologist with both an academic career and a career as a commercial consultant. He was born in Berlin, Connecticut, August 26, 1896 and was educated at the New Britain, Connecticut, High School. Then at Wesleyan University, he earned a Bachelor of Philosophy degree in 1926. He had attended summer school at Harvard in 1925 and went to the American School for Prehistoric Research in Europe during the 1926 summer. He was also a field assistant for the Connecticut Geology and National Historical Survey from 1922 to 1926. He was a laboratory assistant at Wesleyan University from 1924 to 1926 and an instructor there from 1927 to 1928. He was also a laboratory assistant at Yale University from 1926 to 1928. He received an M.S. degree from Yale 1929.

Dr. Wickwire came to Indiana in 1928 to teach at Hanover College becoming Professor Emeritus in 1962. Concurrent with his academic career, he was in active service with the United States of America Army from 1917 to 1919. He was also a Reservist from 1927 to 1933. He did a special study of oil geology from 1936 to 1937 at the University of Cincinnati. Then during World War II, he again joined the Air Force from 1942 to 1945. After the war, he served in the Air Force Reserve from 1945 to 1956 retiring as a Major. He was a member of the Selective Service Board in Jefferson County, Indiana, from 1955 to 1963 and was chairman from 1961 to 1963. He was also an Elder in the Presbyterian Church from 1948 to 1958.

After retirement from Hanover College, Dr. Wickwire moved back to Connecticut to become a consultant for a firm in Old Saybrook. There his work covered general geology, petroleum, and water supply interests.

Prof. Wickwire joined the Indiana Academy of Science in 1928, the year he began teaching at Hanover College. He was honored for his achievements and service to the Academy when he was made Fellow in the spring of 1935. This was a special election when members who were Fellows of the American Association for the Advancement of Science were elected to Fellow in the Indiana Academy of Science. He was Chairman of the Geology and Geography Division in 1942 and on the Executive Committee (now called the Council). He also served on the Program Committee and lectured to a Divisional meeting on "Accelerated Erosion Due to Industrial Waste." Also, he was a Fellow of the National Association of Geology Teachers (President of the West Central Section in 1948 and of the East Central Section in 1956), Fellow of the Geological Society of America, Gamma Alpha, Sigma Gamma Epsilon, and Sigma Xi.

Dr. Wickwire died sometime in 1986. Details of his death could not be obtained, but he had been residing in Eastford, Connecticut, at the time. The honors received from various organizations and the distinction of reaching the rank of Major in the Air Force Reserve added to the versatility necessary to carry out his many activities give us guide posts as to the extent of the full and useful life by this man of 90 years. His biography appears in several publications useful in preparing this report such as Visher's *Indiana Scientists, Indiana Lives* by Hawkins and McClarren (1967), *Who's Who in Indiana,* and *American Men of Science.*

INDIANA ACADEMY OF SCIENCE

NEW MEMBERS—1988

Abell, Sandra K., Education Department, Purdue University, W. Lafayette, IN 47907
Aanderson, John W., Dept. of Life Sciences, Indiana State University, Terre Haute, IN 47809
Anderson, Wm. Tom, Science Dept., Paoli High School, Paoli, IN 47454
Balac, Dragica, 7104 Osborn Avenue, Hammond, IN 46323
Baumgartner, James K., 4901 W. Gadsden St., Indianapolis, IN 46241
Beckman, Roger E., 3300 Browncliff, Bloomington, IN 47401
Bennett, Linda G., 1701 N. Senate Ave., Indianapolis, IN 46202
Benson, Ann A., Tri-State University, Angola, IN 46703
Bluemel, Kevin M., Biology Department, Taylor University, Upland, IN 46989
Bottum, Annette Winter, 4010 Riverside Drive, Columbus, IN 47203
Brewer, Phil, Avis Industrial Corporation, Upland, IN 46989
Broughton, M. Christine, 126 1st Avenue NW, Carmel, IN 46032
Brown, Richard T., Elkhart County Health Dept., 315 S. Second St., Elkhart, IN 46516
Brown, P.E., Jeffrey S., P.O. Box 130, Marshall, IL 62441
Bryant, Susan M., Dept. of Education, Saint Mary's College, Notre Dame, IN 46556
Burton, Kenneth, Biology Dept., Indiana University, Bloomington, IN 47405
Chakrabarti, Debasis, Dept. of Life Science, Indiana State University, Terre Haute, IN 47809
Chess, Karin, Dept. of Mathematics, 8600 University Blvd., Evansville, IN 47712
Collins, Monte W., Chemistry Dept., Indiana University, Bloomington, IN 47405
Coppess, Timothy C., Mississinewa High School, 205 East North H Street, Gas City, IN 46933
Couillard, Joseph Theodore, 40 Wabash College, Crawfordsville, IN 47933
Cristol, Daniel A., Biology Dept., Indiana University, Bloomington, IN 47405
Curry, James R., Dept. of Biology, Franklin College, Franklin, IN 46131
De Groff, Carrie, Bellmont H.S., 1000 E. Adams Drive, Decatur, IN 46733
Delta Faucet Company, *Attn*: Mr. R. Douglas Roland, P.O. Box 40980, Indianapolis, IN 46280
DeMott, William R., Dept. of Biological Sciences, IUPUI-FW, Fort Wayne, IN 46805
DePew, Lori, RR 2, Box 38, Kendallville, IN 46755
Dini, Michael, Dept. of Biological Sciences, University of Nortre Dame, IN 46556
Dolan, Rebecca, Holcomb Research Institute, 4600 Sunset Avenue, Indianapolis, IN 46260
Etchberger, Cory, Dept. of Biology, Indiana University, Bloomington, IN 47405
Firth, Kevin, Taylor University, Upland, IN 46989
Fischer, Robert B., Dept. of Psychological Science, Ball State University, Muncie, IN 47306
Frimpong, Kenneth, Dept. of Biology, Ball State University, Muncie, IN 47306
Fritz, Steven J., Dept. of Earth & Atm Sci., Purdue University, W. Lafayette, IN 47907
Fu, Yen T., Dept. of Mathematics, 8600 University Blvd., Evansville, IN 47712

FURLONG, ELIZABETH, 1320 Sunnymede Ave., South Bend, IN 46615
GAGE, STEPHEN J., Corp. for Science & Technology, One N. Capitol Avenue, Indianapolis, IN 46204
GIBB, TIMOTHY J., Dept. of Entomology, Purdue University, W. Lafayette, IN 46220
GRAY, TERRY, ATEC Environmental Services, 5150 East 65th St., Indianapolis, IN 46220
GRIFFIN, GEORGE ANN, Univ. of Southern Indiana, 8600 University Blvd., Evansville, IN 47711
GUENGERICH, MARK, Goshen College, Goshen, IN 46526
HAMILTON, KEITH, Paul Hadley JHS, 200 W. Carlisle St., Mooresville, IN 46158
HARDY, BRUCE, CRAFT Center, 419 N. Indiana, Bloomington, IN 47401
HASKELL, NEAL H., Dept. of Entomology, Purdue University, W. Lafayette, IN 47907
HEILMAN, JILL, 418 N. Washington, Bloomington, IN 47408
HELLMICH, RONALD P., Dept. of Natural Resources, 605B State Office Bldg., Indianapolis, IN 46204
HELRICH, CARL S., Goshen College, Goshen, IN 46526
HELVERING, LEAH, Dept. of Biology, Ball State University, Muncie, IN 47306
HENMAN, KAREN, 301 S. 25th Street, Terre Haute, IN 47803
HESTER, NORMAN C., Indiana Geological Survey, 611 Walnut Grove, Bloomington, IN 47405
HICKS, TERI ANN, R.R. 1, Flora, IN 46929
HILTON, KATHLEEN H., 4260 S. 6th Street, Terre Haute, IN 47802
HO, JOHNSON, Lincoln Quad R.A., Indiana State University, Terre Haute, IN 47809
HORAN, TIMOTHY T., Jordan Hall, Indiana University, Bloomington, IN 47405
HORKEN, KEMP, 1524 W. Jackson, Muncie, IN 47303
HORN, PAUL W., Department of Psychology, Indiana State University, Terre Haute, IN 47803
IVERSON, GEORGE C., 3900 Soldiers Home Road, W. Lafayette, IN 47906
JACQUART, ELLEN M., Holcomb Research Institute, Butler University, Indianapolis, IN 46208
JANIS, F. TIMOTHY, ICFAR, 611 N. Capital, Indianapolis, IN 46204
JANS, BRIAN, Goshen College, Goshen, IN 46526
JOHNSON, REX R., Marian Heights Academy, P.O. Box 202, Ferdinand, IN 47532
JOHNSON, SCOTT A., Logansport High School, One Berry Lane, Logansport, IN 46947
JONES, MARJORIE MELVIN, Liberal Arts, University of S. Indiana, Evansville, IN 47712
KARN, ROBERT C., Dept. of Biological Sciences, Butler University, Indianapolis, IN 46208
KING, RICHARD B., Department of Biology, Indiana University, Bloomington, IN 47405
KINSEY, DAVID W., Mathematics Dept., Univ. of Southern Indiana, Evansville, IN 47712
KREPS, DAVID P., P.O. Box 51, Manchester College, N. Manchester, IN 46962
KROPF, JEREMY, Goshen College, Goshen, IN 46526
LABHART, MARJORIE O., Univ. of Southern Indiana, 8600 University Blvd., Evansville, IN 47712
LAHERTY, RICHARD F., THCME, Indiana State University, Terre Haute, IN 47809

Lang, Patricia L., Department of Chemistry, Ball State University, Muncie, IN 47306
Leeper, Brian S., 505 Schmitt Ct., Apt. 3, Mishawaka, IN 46544
Lehmer, Lynne, Goshen College, Goshen, IN 46526
Lindberg, Holly, 3425 Kent Lane, South Bend, IN 46615
Litwin, Michael S., U.S. Fish & Wildlife Service, 718 N. Walnut, Bloomington, IN 47401
Livingston, Stan, Soils Building, Purdue University, W. Lafayette, IN 47906
MacRury, Thomas, Pitman-Moore, Inc., 9315 Sanders Road, Northbrook, IL 60062
Madej, Robert F., Dept. of Biology, Indiana University, Bloomington, IN 47405
Martin, Michelle L., Div. of Nature Preserves, 605B State Office Building, Indianapolis, IN 46204
Masin, Melanie, 537 Chamberlin Drive, South Bend, IN 46615
Mason, James H., R.R. 15, Box 441, W. Terre Haute, IN 47885
Mason, Mrs. James H., R.R. 15, Box 441, W. Terre Haute, IN 47885
Massanari, Eric, Goshen College, Goshen, IN 46526
McCall, Claire, Biology Dept., Valparaiso University, Valparaiso, IN 46383
McClung, Timothy W., NWS/NOAA, Michiana Airport, 4475 Terminal Drive, South Bend, IN 46628
McIntyre, James R., Poultry Science, Room 220, Purdue Univerity, W. Lafayette, IN 47907
McNarney, Martin, 1202 Rosemary Lane, South Bend, IN 46617
Meunier, Jo Ann, Biology Dept., Ball State University, Muncie, IN 47306
Meyertholen, Edward P., Dept. of Physiology & Health Science, Ball State University, Muncie, IN 47306
Miller, Stuart, 709 W. Wayne St., Middleburg, IN 46540
Model, Sean M., 2116 Idaho St., Terre Haute, IN 47802
Molchan, Nicholas G., Marshall County Health Dept., 112 W. Jefferson, Box 462, Plymouth, IN 46563
Moloney, Anne, R.R. 51, Box 629, Terre Haute, IN 47805
Nekvasil, Nancy, Biology Department, Saint Mary's College, Notre Dame, IN 46556
Nice, Kathy J., Huntington College, Huntington, IN 46750
Nichels, Kevin, 6506 Whippoorwill Lane, Lafayette, IN 47905
O'Donnel, Colleen M, 352 Riveredge Dr., Romeoville, IL 60441
Olsen, T. Mark, Dept. of Biological Sciences, University of Notre Dame, Notre Dame, IN 46556
Papenmeier, Gerald J., Marion County Health Dept., Room G8, City-County Bldg., Indianapolis, IN 46204
Parka, Stanley J., Environmental Affairs Div., Eli Lilly and Company, Indianapolis, IN 46285
Parker, Allen R., Div. of Fish & Wildlife, 300 W. 1st, Bloomington, IN 47401
Patrick, Randy R., R.R. 2, Box 212A, Roachdale, IN 46172
Pauly, Steve, Geology Department, Indiana University, Bloomington, IN 47405
Phan, See-Eng, 927 Weber Square West, South Bend, IN 46617
Pohl, Victoria, Univ. of Southern Indiana, 8600 University Blvd., Evansville, IN 47712
Pursell, F. Allen, Dept. of Forestry & NR, Purdue Univeristy, W. Lafayette, IN 47907

Radich, Paul C., Univ. of Indianapolis, 1400 East Hanna Ave., Indianapolis, IN 46227

Raines, Steven R., 309C Harrison Hall, DePauw Univeristy, Greencastle, IN 46135

Randall, Walter C., Biology Department, Taylor Univerity, Upland, IN 46989

Redman, Gary, Univ. of Southern Indiana, PAC 309, 8600 University Blvd., Evansville, IN 47712

Rempel, Theresa S., 825 W. Hampton Drive, Indianapolis, IN 46208

Renner, Chris, New Castle High School, 801 Parkview Drive, New Castle, IN 47362

Renshaw, Ronald, 59481 C.R. 9 South, Elkhart, IN 46517

Rhodes, Samuel B., Biology Department, Franklin College, Franklin, IN 46131

Richey, Kris D., A.R.M.S., Ball State University, Muncie, IN 47306

Riddle, John C., Caleb Mills House, Wabash College, Wabash, IN 47933

Riegle, Daryle E., MSC-26, Vincennes University, Vincennes, IN 47591

Rouch, John H., Fairfield Jr.-Sr. H.S., 67530 US 33, Goshen, IN 46526

Rudman, Albert J., Geology Department, Indiana University, Bloomington, IN 47405

Saxon, Herbert, Dept. of Biology, Ball State Univerity, Muncie, IN 47306

Scanlan, Christopher, 929 Bellevue Ave., South Bend, IN 46615

Schilke, Angela J., Cooper Sci. Building, Ball State University, Muncie, IN 47306

Schmidt, John M., Jordan Hall 29, Indiana University, Bloomington, IN 47401

Schubert, Christopher E. K., Indiana Geological Survey, 611 N. Walnut Grove, Bloomington, IN 47405

Schurz, Helen, Dept., of Chemistry, Indiana University, Bloomington, IN 47405

Scupham, David W., Biology Dept., Valparaiso University, Valparaiso, IN 46383

Seevers, Kurt P., 124 Entomology Hall, Purdue University, West Lafayette, IN 47907

Shafer, Tracy, Huntington College, Huntington, IN 46750

Shaw, Marlene, Dept. of Biology, Univ. of Southern Indiana, Evansville, IN 47712

Smith, David A., Dept. of Biology, Wabash College, Crawfordsville, IN 47933

Smith, Denny, Taylor University, Upland, IN 46989

Spacie, Anne, Forestry Building, Purdue University, W. Lafayette, IN 47907

Steele, Fintan, O.S.B., Dept. of Biological Sciences, University of Notre Dame, Notre Dame, IN 46556

Stegemoller, William, Univ. of Southern Indiana, 8600 University Blvd., Evansville, IN 47712

Steinmetz, Curtis, Dept. of Chemistry, IUPUI, Indianapolis, IN 46223

Stott, Diane E., USDA-ARS, Nat. Soil Erosion Res. Lab., Purdue University, Bldg. SOIL, W. Lafayette, IN 47907

Straub, Craig, Delta Apt. 3B, Taylor University, Upland, IN 46989

Surface, Esther, 1709 N. New York, Muncie, IN 47304

Sweeten, Jerry, Asherwood Envir. Learning Ctr., R.R. 3, Box 214, Wabash, IN 46992

Thomas, Marcy, 310 North Auburn Street, Indianapolis, IN 46224

Thorne, David H., 120 Forestry Bldg., Purdue University, W. Lafayette, IN 47907

Tucek, David, NWS/NOAA, Michiana Airport, 4475 Terminal Drive, South Bend, IN 46628

Uhl, Susie, Dept. of Earth & Atmos. Science, Purdue University, W. Lafayette, IN 47907

VIETS, BRIAN E., Dept. of Biology, Indiana University, Bloomington, IN 47405
VINSON, JAMES S., Univeristy of Evansville, 1800 Lincoln Avenue, Evansville, IN 47722
VOLKMAN, MARK J., Physics Department, Purdue University, West Lafayette, IN 47907
WAGOR, WALTER F., Dept. of Psychology, IU-East, 2325 Chester Blvd., Richmond, IN 47374
WALLACE, JAN M., 9380 E. 700S, Upland, IN 46989
WALLS, TINA, 2261 Biscay Square, Indianapolis, IN 46260
WALTZ, ROBERT, 613 State Office Bldg., Indianapolis, IN 46204
WATSON, LEE R., 5957 Lakeside Blvd., Indianapolis, IN 46278
WATSON, M. DESIREE, Indiana-Purdue University, Fort Wayne, IN 46825
WAUGH, JENNIFER, R.R. 1, Box 350, McCordsville, IN 46055
WELLS, JUDITH A., Univ. of Southern Indiana, 8600 University Blvd., Evansville, IN 47712
WELLSO, STANLEY G., 3805 Capilano Drive West, West Lafayette, IN 47906
WENTWORTH, RUPERT A.D., Department of Chemistry, Indiana University, Bloomington, IN 47405
WHIPPLE, ANDREW P., Dept. of Biology, Taylor University, Upland, IN 46989
WHITMAN, RICHARD, Biology Department, Indiana Univ.-NW, Gary, IN 46408
WILKIN, PETER J., Biology Department, Purdue Univ.-Calumet, Hammond, IN 46323
WILLIAMS, PAULA D., R.R. 1, Box 148, Alexandria, IN 46001
WILLIAMS, THOMAS B., 425 Agnes Street, Indiana Univ. at Indianapolis, Indianapolis, IN 46202
WONG, DONALD, Dept. of Anatomy-Med Sci 204, IU Medical School, Indianapolis, IN 46202
WOOD, ROSEMARY, 4600 Sunset Avenue, Indianapolis, IN 46208
WYMAN, DOROTHY L., Madison Heights High School, 4610 Madison Avenue, Anderson, IN 46013
XU, LEI, Biology Department, Univ. of Notre Dame, Notre Dame, IN 46556
ZIMMEL, BRIAN, R.R. 2, Box 185, Velpen, IN 47590
Belmont High School, 1000 E. North Adams Drive, Decatur, IN 46733
Caston High School, R.R. 1, Box 128, Fulton, IN 46931
Fairfield H.S. Science Club, 67530 U.S. 33, Goshen, IN 46526
Grimmer Middle School, % Marjorie Thompson, 225 W. 77th Avenue, Schererville, IN 46375
Lake Central High School, Science Club, 8400 Wicker Avenue, St. John, IN 46373
Linton-Stockton H.S., Science Club, 801 NE H Street, Linton, IN 47441
Linton-Stockton Junior H.S., Science Club, 109 NE I Street, Linton, IN 47441
North Daviess Jr. H.S., Science Club, R.R. 1, Elnora, IN 47529
South Wayne J.H.S., Science Club, 4901 Gadsden, Indianapolis, IN 46241
Vincennes Lincoln H.S., Science Club, 3001 Hart Street, Vincennes, IN 47591
Yorktown H.S., Science Club, 700 E. Smith, Yorktown, IN 47396
Young Middle School, Science Club, 1801 E. Main, Mishawaka, IN 46544

Proceedings
# of the
Indiana Academy
# of Science

Part II

Addresses and
Invited Papers

SPEAKER OF THE YEAR ADDRESS—1988-89

INDUSTRIAL MINERALS—A CRITICAL KEY TO ECONOMIC DEVELOPMENT

HAYDN H. MURRAY
Speaker of the Year
Department of Geology
Indiana University
Bloomington, Indiana 47405

ABSTRACT: Industrial or non-metallic minerals are essential to economic development. The value of industrial mineral production in the United States is over 3 times the value of metallic mineral production. In the developed countries of the world, the value of non-metallic mineral production exceeds the value of metallic mineral production. The development of a modern industrialized society requires quality and reasonably priced industrial minerals in such industries as smelting of copper and iron, manufacturing cement, drilling oil wells, manufacturing ceramic materials, and a host of others. Because transportation costs are high, most industrial minerals are not imported so a country or region must have a good raw material source.

INTRODUCTION

A precise inclusive definition for industrial minerals or non-metallic minerals is difficult because it includes many unrelated minerals that range from low priced materials such as sand and gravel to high priced materials like industrial diamonds. The World Bank report (Noestaller, 1987) defines industrial minerals as comprising all non-metallic non-fuel minerals extracted and processed for industry end uses, some metallic minerals consumed in non-metallurgical applications, and consolidated and unconsolidated rock materials (e.g., sand, gravel, crushed rock, and dimension stone) and manufactured products (e.g., cement and refractories). The Mining Journal (1988) classifies industrial minerals into three economic groups: (1) low-price, large volume commodities such as sand, gravel, and construction materials; (2) medium to high-price, large volume commodities such as chemical and fertilizer minerals (e.g., salt, sulfur, phosphate, and potash); and (3) high price, small volume commodities such as fluorspar, talc, barite, and industrial diamonds.

The low value, high volume construction type materials are mainly used locally, and generally achieve their maximum use in the stage of popultion growth and the economic development of an area. The high value, low volume industrial materials are used in the more industrialized nations and are often traded internationally. A measure of industrial maturity is achieved when the value of industrial or non-metallic minerals and rocks exceeds that of metallic minerals. This point was reached in the United States early in this century and today the value of the industrial minerals and rocks is about 3 times that of the metallic minerals. Australia just reached this point in the 1980's.

The standard of living in a particular country or area of the world correlates with the availability and production of industrial minerals. The United States, which has a very high standard of living, has an ample supply of most industrial minerals. Without their availability at a reasonable price, the U.S. could not have achieved this high standard of living nor its tremendous industrial growth. The same can be said of Western Europe.

As mentioned before, there is a great diversity of values for industrial minerals. These values range from a few dollars per ton for sand, gravel, and mineral aggregates such as limestone to several million dollars per ton for industrial diamonds. There is also a great diversity in the utilization of industrial minerals. Our building and process industries require quality and reasonably priced industrial minerals. These minerals are an integral and functional part of many, many products such as cement, ceramics, paper, paint, plastics, and a host of other manufactured products. The growth of the non-metallic or industrial minerals correlates to a large extent with the increase of our gross national product (GNP)

INDUSTRIAL UTILIZATION OF NON-METALLIC MINERALS

Industrial minerals are necessary in many industries as mentioned above. Some examples of the minerals that are used and what they contribute to the manufactured products are given as follows. This is by no means complete but does indicate the diversity and functionality of these important industrial minerals.

The building industry could not function without industrial minerals. Cement, which is a necessary component of most of our buildings, is made from industrial minerals that include limestone and shale which is pulverized, mixed together in specified proportions, and heated to form the necessary reaction products that make cement. In buildings and roads the cement is mixed with aggregate which can be sand and gravel or a mineral aggregate such as limestone or trap rock (basalt). If a lightweight concrete is needed then a lightweight aggregate such as bloated shale is used. This bloated shale is formed by rapidly heating crushed shale particles to a temperture in which some volatiles in the shale are released at the same time the surface of the shale particle is melting. The volatiles then form internal voids because they expand when trapped by the viscous glassy outer melted surface. When cooled the shale particles are strong and light in weight and make a good lightweight aggregate for concrete. Other building materials also use industrial minerals. These include wallboard which is made from gypsum, bricks which are made from clays and shales, dimension or building stone which are limestone, marble, granite, and many other rocks, plaster which uses cement and perlite, and tile which uses kaolin, talc, wollastonite, and other minerals.

In making iron and steel, a flux is needed to lower the melting point of the iron ore. This flux is usually high calcium limestone. In making metallic aluminum, a flux normally used is fluorite, another industrial mineral. In smelting copper, an industrial mineral silica sand is used as a flux. Therefore, industrial minerals are necessary in the smelting of metallic ores.

In drilling oil wells. industrial minerals play a very important role. A drilling mud is necessary in order to successfully drill an oil well because the drilling mud is used to carry the tons of rock cuttings up the hole to the surface, it seals the hole by forming an impermeable layer of mud cake on the side of the hole thereby preventing the drilling fluid from escaping into the permeable and porous rock formations, and the mud cools and lubricates the drill bit. The drilling mud is comprised of industrial minerals, the major component of which is usually sodium bentonite. The material when mixed with water forms a material which is fluid when agitated or stirred and is gel-like when allowed to set. This property is called thixotropy. When the mud is pumped down the hole through the drill pipe to the bit it is fluid but is viscous enough to carry the rock cuttings up the hole. If the drilling stops for some reason the drilling mud becomes a gel which prevents the rock cuttings from settling to the bottom and binding the drill bit so that it would twist off when the drilling was started again. Sodium bentonite is naturally thixotropic so is used for drilling oil wells all over the world and is an absolutely essential ingredient. In deep drilling to several thousands of feet the pressure of fluids in the rock formations are very high and if gas or oil is encountered that is under high pressure, the drilling mud could be blown out of the hole and dangerous fires would occur. In order to prevent these blow-outs, a weighting material is used. This finely pulverized heavy material is mixed with the drilling mud to make it heavy enough to contain the bottom hole pressures from blowing out the hole. The most common weighting agent is the industrial mineral barite which is very heavy.

Ceramic materials, which are used extensively in our everyday lives, are made from industrial minerals. Fine china is made using kaolin, silica, and feldspar in proper proportions. Pottery is made from clays and other industrial mineral ingredients. Refractories, for lining high temperature furnaces, use various refractory industrial minerals including kaolin, kyanite, dolomite, silica, and chromite. Glass, which is classed as a ceramic material, is made from high silica sand or quartzite along with a flux such as soda ash. Think of how much glass is used in your homes, cars, and office buildings. This means that it requires the availability of large quantities of high quality silica sand in various parts of the country to sustain our glass manufacturing industry.

Think of how much paper is used every day in your homes and offices. Paper is made from wood pulp but also requires other ingredients which are mainly industrial minerals. Paper requires fillers to give it certain needed properties including whiteness, printability, smoothness, and opacity (hiding power). Industrial mineral fillers are used to give these properties and include kaolin, calcium carbonate, silica flour, talc, and titanium dioxide. For color printing, such as in *National Geographic Magazine*, the paper must be coated and this coating is normally kaolin and/or calcium carbonate along with a minor quantity of titanium dioxide. *National Georgaphic Magazine* is about 35% by weight the industrial mineral kaolin.

In the foundry industry industrial minerals are essential in making the molds into which the molten metal in poured. The engine block in your automobile is made by pouring the hot gray iron into a mold which is made primarily of silica sand and bentonite clay. The mold must be strong enough to hold the molten metal, porous enough to release the gases from the molten metal as it cools, and refractory enough so that it doesn't melt and contaminate the iron. These two industrial minerals, high silica sand, which is the major component, and bentonite, have the needed properties to make these molds.

Industrial mineral fillers are used in many products including paint, plastics, rubber, and ink. These fillers are not inert fillers but they perform a needed function. Fillers or extenders in paint make the paint film glossy or dull, washable, and smooth, and gives the paint film covering power and body so that it doesn't drip or run. In plastics, mineral fillers make the plastic less brittle so that it does not shatter on impact, makes many plastic materials less vulnerable to infra-red and ultra violet degradation and improves the surface smoothness of the plastic. Some automobile bodies and many boat bodies are made of plastic and contain up to 40% mineral filler, usually calcium carbonate or kaolin. Without the mineral filler the plastic would shatter like glass upon impact. In rubber, industrial mineral fillers are used to improve abrasion resistance, to stiffen the rubber product, to reduce the elasticity, and improve the hardness. In ink, fillers are used to control the viscosity and to improve the covering power. Thus, it can be seen that industrial mineral fillers are a necessary and functional part of many industrial products.

Another area where industrial minerals are used is when a sorptive material is needed. Examples are in machine shops where oil spills commonly occur or in service stations where motor oil is spilled on the floor. An absorptive clay is used to soak up this oil. This type of clay is commonly referred to as fullers earth. These sorptive clays are also used in the agricultural area as carriers for insecticides and pesticides. The largest use by far of these sorptive clays is as cat litter. Over a million tons of this clay are used annually in the United States by cat owners.

There are many, many other industrial uses for many other industrial minerals. The aforementioned examples are only to illustrate how important the industrial minerals have been and are to our industrial development.

LOCATION AND TRANSPORTATION

The location of the low price, high volume industrial minerals with respect to the markets is exceedingly important. In general, the transportation cost of these low priced industrial minerals such as sand and gravel control their marketability because in many cases the transportation cost exceeds the cost of the sand or gravel at the mine. This is the reason that the mines must be located as close to the markets as possible. The urban growth around every major city in the United States has limited the expansion of operating mines and prohibited opening up new mines because of zoning restrictions. Thus, the delivered cost of sand and gravel has increased significantly in most major cities because of the increased cost of transportation. Policy develoment regarding this resource should begin to recognize: (1) the necessary of having a viable sand and gravel industry; and (2) the need to locate and protect these resources needed for the future.

The medium to high price, large volume commodities and the high price, small volume industrial minerals are relatively insensitive to transportation costs although in many cases it is a marketing factor. The high cost of transportation gives considerable incentive to explore and locate resources nearer to markets. In many instances lower quality materials are located and because of the lower transportation cost additional money can be spent on processing to bring the product into market specifications.

INDIANA'S INDUSTRIAL MINERALS

The industrial minerals produced in Indiana are many and their value is substantial. In 1987, the value of the industrial minerals production in Indiana was $363,900,000. Indiana's industrial minerals actually fall into all three classifications enumerated in the introduction and are as follows:

1. Low value, high volume
    - sand and gravel
    - limestone aggregate and agricultural lime
    - brick clays
    - foundry sand and glass sand
    - marl
    - gypsum
2. Higher value, high volume
    - dimension limestone
    - high calcium limestone
    - filler clay and white firing ceramic clays
    - peat
3. High value, small volume
    - whetstone

Sand and gravel pits are located in all regions of Indiana with the largest concentration of operations in the vicinity of Indianapolis. Limestone aggregate and ag lime operations are also located in all regions of Indiana so that the transportation costs of these low value materials are minimal. Limestone for cement is mined near Greencastle, Mitchell, and Speed.

Brick clays are found in many areas of Indiana although only one plant south of Mooresville is now operating. Marl for agricultural use is mined in northern Indiana near LaPorte. Foundry sand pits are located near Attica and in the Dunes along the south shore of Lake Michigan.

The production of gypsum in Indiana ranks higher than any other state. The location of the two mines producing this important industrial mineral is near Shoals in Martin County, Indiana. The reason for the large production is location. Chicago, St. Louis, Louisville, Cincinnati, and Detroit are large markets for wallboard, which is the major product in which the gypsum is used.

The famous Indiana limestone, which is superior building stone, is quarried in the area between Bloomington and Bedford. This industry is producing at capacity at present and the outlook is rosy for the foreseeable future.

High calcium limestone is produced at five locations, Swayzee, Stinesville, Indianapolis, Orleans, and Leavenworth. The high calcium limestone is used as a flux in the steel industry and as a filler in many process industries. Filler clays and white firing ceramic clays are produced at Huntingburg, Indiana. The filler clay is used in asphalt, rubber, and plastics. Peat is produced in northern Indiana at several locations in Allen, LaPorte, Hamilton, and Madison Counties. The peat is used mainly as a soil conditioner. Natural whetstones are mined and shaped at a small operation near Orleans in Orange County. This is the only high value, low volume product produced in Indiana and it is classed as an abrasive.

SUMMARY

Industrial or non-metallic minerals are relatively unheralded materials but have a much higher value in the United States than the metallic minerals. They are essential ingredients in many process industries including paper, paint, plastics, rubber, ceramic, cement, glass, and many others. Our high standard of living is largely due to our abundant supply of quality industrial minerals. Location and transportation costs are very important for the low cost, high volume industrial minerals and are relatively inconsequential for the higher cost, high volume and high cost, low volume industrial minerals.

Indiana's industrial minerals are important to the state's economy. One of the most important industrial minerals is gypsum and the production in Indiana is larger than that of any other state. Our building construction and agricultural areas are healthy because of the abundance of local sources of sand, gravel, and limestone. The Indiana limestone that is shipped throughout the United States for use as a dimension building stone is an important industry in the Bloomington and Bedford areas. Thus, we can see that industrial minerals are truly a critical key to economic development.

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Part III

Section Meetings and Contributed Papers

ANTHROPOLOGY

Chair: Ruth Brinker
Division of Reclamation
P.O. Box 101
Jasonville, Indiana 47438

Chair-Elect: Curtis H. Tomak
2145 Glenn Drive
Martinsville, Indiana 46151

ABSTRACTS

Overview of Archaeological Activities Conducted by the Indiana State University Anthropology Laboratory. C. Michael Anslinger, C. Russell Stafford, Robert E. Pace, and Mark E. Cantin, Indiana State University, Anthropology Laboratory, Terre Haute, Indiana 47809.———In 1988 the Indiana State University Anthropology Laboratory completed excavations of the Middle-Late Archaic Bluegrass Site (12W162) in Warrick County, and also undertook excavations at 12Gr615 and 617, multicomponent sites located along Lattas Creek in Greene County. The Darwin Site (11C12) a large multicomponent habitation site with mounds was also examined, with Middle and Late Woodland and Mississippian components being identified. In addition, the Data Center Study Reconnaissance Project neared completion, with over 20,000 acres having been systematically examined to date. A variety of data gathered during the project are being computerized.

Redefinition of Several Upper Mississippian and Lower Pennsylvanian Chert Types of Southern Indiana. Mark Cantin, Indiana State University, Anthropology Laboratory, Terre Haute, IN 47809 and Kenneth B. Tankersley, Indiana University, Glenn Black Laboratory of Archaeology, Bloomington, IN 47401.———This paper attempts to provide more accurate definitions of several chert types of Indiana occurring in Upper Mississippian to Lower Pennsylvanian units. Research involved includes field reconnaissance and sampling, stratigraphic correlation, macroscopic description, and microscopic petrographic analysis. Results of this study applies new and more proper nomenclature to the types described and restructures the occurrence of the types in the stratigraphic column.

Marine Shell Beads from Archaic and Woodland Contexts in Indiana. Curtis H. Tomak, Indiana Department of Highways, State Office Building, Indianapolis, IN 46204.———Shell beads are known from Archaic, Woodland, and Mississippian contexts in Indiana. Accurate and sufficiently specific biotaxonomic identification of the shells can provide data relating to trade, contact, and movement of peoples. Problems and confusion exist, however, as a result of differences of opinion regarding the species or genus of particular marine shell beads, controversies over whether or not certain beads are marine or freshwater, and misidentifications which appear in the archaeological literature. This paper discusses marine shell beads from an Early Archaic Jerger Phase site, Late Archaic sites, and Late Woodland Albee Tradition sites in Indiana and addresses the above mentioned difficulties. Biotaxonomic identifications of beads were made for this project by Mr. and Mrs. William B. Adams of Bloomington, Dr. James R. Dodd of the Indiana University Department of Geology, and Dr. William K. Emerson of the American Museum of Natural History.

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ZOOARCHAEOLOGY AT INDIANA UNIVERSITY: THE PAST, THE PRESENT, AND THE FUTURE

William R. Adams and Janis K. Kearney
Department of Anthropology
Indiana University, Bloomington, Indiana 47405

Zooarchaeology, variously called ethnozoology, faunal ethnology, and archaeozoolgy, refers to the identification and analysis of animal remains recovered archaeologically as a means of understanding relationships between man and his zoological environment. Zooarchaeology is said to have had its origin in North America in the 1860's, but only in recent years have related articles become more common in the literature. The early years from the late 1860's to the early 1950's was a time of practice, testing, evolution, growth, and expansion of the field. Animal bone fragments *per se* held little interest for either archaeologists or for exhibit visitors. They also occupied large amounts of storage space, and thus it was commonplace to discard them on the waste piles during excavation with only minimal mention in the field notes. This usually consisted of a 'laundry list' of species found and relegated to the appendix of an archaeological report. Little attempt was made to actually interpret the data.

Biologists and zoologists seldom had more than a passing acquaintance with the skeletal aspects of the multitude of vertebrate species in their own geographic area of study, much less those of some distant area. Adequate comparative materials were few and far between and often unavailable because of time restraints and travel expense.

During the early twentieth century, some promising attempts were made to identify worked bone to species level and skeletal element. Food resource species, bone artifacts, and their probable manner of usage were described. This was a new and significant approach. Some of these ideas and procedures, which helped to further the field of zooarchaeology, are briefly mentioned below.

Wintemberg (1919) foresaw the future importance of zooarchaeology and pointed out the value of archaeological remains to the zoologist as a means of providing information on range expansions and contractions, environmental adaptations, morphological variations, extinctions, and pathologies. His suggestions, too advanced for the time, were not widely accepted, and many archaeologists still looked on faunal remains as lacking significant data potential.

One of the important early zooarchaeological works was the publication of Loomis and Young (1912) in which they attempted to identify all faunal material to species level and bone element. Descriptions of butchering methods, site seasonality (a new concept), dietary significance, and observations on types of dogs found were presented in the form of charts for the first time.

The first site-comprehensive report was Baker's (1923) attempt to synthesize an overall dietary analysis with interpretations of aboriginal use. Bockelman (1936,1937) proposed that archaeologists save all marine shell fragments, in anticipation of possible reconstruction of primitive trade routes. This was reinforced by Hargrave's (1938) plea, with well-expressed justifications, for archaeologists to preserve all bone material.

The 1930's were a time of numerous massive excavations conducted through government support, most noticeably through the Works Progress Administration (WPA). This support enabled Glenn A. Black to pursue extensive excavations at the Angel Site in southern Indiana. Unfortunately, little was published dealing with faunal specimens recovered during these excavations.

In the late 1940's, Taylor (1948) stressed the importance of accurate cultural analyses and encouraged archaeologists to collect and analyze more faunal material. Zooarchaeologists continued to systematize their methods by presentation of tables, by listing of species by archaeological unit, and by attempting to understand the sources, manufacturing techniques, uses of mundane, exotic and ceremonial artifacts, butchering methods, seasonal habitation patterns, hunting methods, and environmental changes.

The dearth of adequate collections of comparative skeletal specimens had long hampered accurate and complete analyses, but eventually zooarchaeologists began to build extensive collections of comparative skeletons and to publish handbooks and guides to animal bone identification. Lawrence (1951), Olson (1960), Gilbert (1980), Gilbert, Martin, and Savage (1981), Brown and Gustafson (1979), and White (1952,1953,1954,1955) published on butchering methods, meat yields, and species importance. Guilday (1958,1963,1969,1970), Olsen (1964), and Parmalee (1959,1960,1965,1968,1973) together and separately published a large number of papers describing identifications they were able to make through the use of their own large comparative collections. However, faunal analysis data were still not generally incorporated into archaeological reports.

In 1969, Howard Winters' use of an integrated interdisciplinary approach to obtain an ecological interpretation of the Riverton Culture was followed by numerous papers making similar use of integrated sciences. At the same time, other researchers were examining, critiquing, and improving zooarchaeological methods, theories, and ideas.

The early 1940's saw the beginnings of zooarchaeology in Indiana. Glenn A. Black believed that the large number of bone fragments being excavated at the Angel Site should be used to extend our understanding of that prehistoric culture. With this in mind, he began a rudimentary comparative collection by saving several dozen bones previously identified by Bob Goslin at the Ohio State Museum. Aware of Adams' interest in both animals and bones, Black, with the approval of Eli Lilly, encouraged Adams to spend part of his field survey time in the collection and preparation of a comparative collection that could be used to identify excavated bone fragments. At that time, there were only a few individuals in the United States engaged in identification and interpretation of archaeological faunal material. Black subsequently requested Adams to undertake a study of the Angel Site faunal assemblage. Additional emphasis was placed on recovery and preservation of all bone fragments from Angel Site. Since that time, there have been several small reports written on the identification of Angel Site faunal material (Adams, 1949, 1950), but a significant portion of the bone fragments has yet to be identified.

Over the next two years, a considerable amount of Adams' time was spent collecting faunal specimens through fishing, hunting, and trapping in Warrick, Vanderburg, Perry, Posey, Monroe, Owen, and Brown Counties. Additional animal carcasses were obtained from other trappers, fishermen, hunters, pet shops, zoos, and roadkills. In the beginning, these specimens were processed by cooking in a caustic lye solution either on a backyard fireplace at home or on a hot plate in the Angel Site laboratory.

In 1947, Adams returned to Bloomington to pursue graduate work, teach anatomy, and continue to enlarge and develop the collection. Summer vacations of three to twelve weeks, spent in northern Minnesota, enabled the acquisition of hundreds of specimens, many representing species rare or absent at that time in Indiana, such as deer, bear, wolf, coyote, porcupine, and beaver, as well as numerous bird species found in Indiana only during rather brief spring and fall migrations. Additional collecting was carried out in the Arctic, Arizona, Missouri, and Illinois.

Especially encouraging during the early development of the Zooarchaeology Laboratory at Indiana University were Barbara Lawrence of the Peabody Museum, Bob Goslin of the Ohio State Museum, Paul Parmalee of the Illinois State Museum, John McGregor of the University of Illinois, Clara Bartlett of the Museum of Northern Arizona, Ken Kidd of the Royal Ontario Museum, Georg E. Neumann of Indiana University, and Eli Lilly of the Indiana Historical Society.

Adams' appointment to the faculty of the Department of Anthropology in 1955 was accompanied by the move of the laboratory from the basement of his home into an old house just off campus and shared with physical anthropologist Georg K. Neumann. Here, the laboratory was furnished with electric hot plates, a sink, an old ice cream freezer, shelving, and several library tables for layout work. A large number of specimens were processed during the 1955–1962 period through the efforts of many students who contributed countless hours of volunteer effort.

In 1962, the laboratory was again moved; this time to the third and fourth floors of Rawles Hall, quarters recently vacated by the Geography and History Departments. A large wet lab with exhaust fan, sink, freezer, and work table was set up on the fourth floor. Here, comparative skeletons were prepared by cold water maceration, a time consuming process which consisted of immersing an animal carcass in cold water and letting it decompose with a change of fresh water every two or three days. In the late 1970's, use of hot water baths accelerated the processing of specimens but also generated even more unpleasant and copius odors, occasionally forcing temporary evacuation of many offices in the building. It was later realized that, through an engineering oversight, the room exhaust had not been vented to the outdoors. Instead, it emptied into an attic area, where odors were quickly picked up and distributed by the general air ducting of the building. Various changes and improvements took place through the years but only recently, with installation of 'state of the art' air handling equipment, have they proved adequate to solve the odor problems.

Now, all odor-producing procedures are routinely carried out in one of the two eight foot laboratory fume hoods, which are exhausted through a hydraulic scrubber/filter. The system is automatically balanced to provide for adequate make-up air. Each hood contains a sink and heavy duty disposal, although most waste must be frozen for later incineration.

The Laboratory currently houses a large collection of disarticulated skeletons of mammals, birds, reptiles, amphibians, and fish, which are used to teach faunal osteology and for identification of large assemblages of skeletal fragments recovered from archaeological sites. While the collection currently includes few articulated skeletons, the number continues to grow annually through various student projects. Through the years, the Zooarchaeology Laboratory's comparative collection has grown to over 4,600 vertebrate specimens and some 110,000 invertebrate specimens, many of which are no longer readily available for collection purposes due to extinction or endangerment. It is one of the larger comparative collections in the United States devoted to zooarchaeological analysis and available for both teaching and research.

The collection is continually being enlarged to make skeletal series demonstrating species, age, sex, individual, and pathological differences available to researchers. The efforts of the laboratory personnel (both paid and volunteer) have long been limited to processing the increasing numbers of newly acquired specimens, while comparatively few monetary resources have been directed toward curation and conservation of specimens previously processed. In recent years, the comparative collection has shown increased signs of deterioration due to this long-term financial neglect. This has resulted in visible degradation of numerous specimens and containers, mildew and mold formation, insect infestation, cracking and crushing of specimens, and loss of label information regarding skeletal specifics making it very difficult to maintain an update of the manual catalog system.

The laboratory is also hampered by inadequate work and storage space, a fourth-floor location with no elevator, and insufficient monetary resources to hire the needed technical help or buy necessary supplies. Additionally, specimens are currently stored in a wide range of makeshift containers including small plastic jewelry boxes, shoe boxes, apple boxes, medicine vials, and everything in between.

In view of the numbers and sizes of animals made available by conservation agencies, zoos, and sportsmen, the present fourth floor location of the laboratory has become increasingly inconvenient. Currently, specimens of 50 lbs to 300 lbs (such as deer, polar bear, zebras, tigers, sheep, goats, wolves, and pythons) have to be carried up the stairs to the dissection laboratory, and subsequently, entrails, flesh, and skins carried back downstairs for transport to an incinerator across campus. These physical restrictions have necessitated the refusal of several large and valuable animal carcasses, which were needed to fill gaps in the collection.

Two academic classes are offered to introduce students to the field of zooarchaeology, and a third class examines the many uses of fauna and flora by aboriginal groups. Additionally, students may enroll in research and reading classes to pursue special research interests.

The large number of skeletal identifications (Adams, 1949, 1950, 1980, 1981; Adams, *et al.*, 1987a,b,c,d) from prehistoric and historic archaeological sites and the forensic identifications that the Laboratory is requested to perform each year by law and wildlife enforcement agencies, farmers, construction contractors, and private individuals present a tedious and time consuming process, but one that provides valuable practical experience for students. Future plans for the Zooarchaeology Laboratory at Indiana University call for a number of changes:

1. Computerization of the laboratory's catalog and related specimen information on a database management system in the immediate future will

permit the collections to be more readily accessed by interested researchers and laboratory personnel. Also, database computerization of faunal assemblages, as they are identified and analyzed, will allow faster and more accurate manipulation of data and will consequently result in more timely report production.

2. The grossly inadequate physical environment of the laboratory will be greatly improved in a proposed move, scheduled for the summer of 1990, to a newly renovated facility. This move should allow more rapid and efficient preparation of comparative specimens (including large ones), an improved capability for zooarchaeological analyses, and a much improved teaching environment.
3. The proposed move should eventually permit a staff increase with the opportunity for more broadly based zooarchaeological research and publication. This proposed upgrade will enable the ultimate establishment of a zooarchaeological institute at Indiana University.

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ADDENDUM

Since the preceding paper was presented and submitted for publication some four years ago, many changes have taken place. The proposed move of the laboratory scheduled in 1990 could not be realized because of delays in planning and financing and later by a disastrous December fire in the Student Building during it's renovation.

The long-awaited move was made in early August, 1991 and will be described in detail in a future paper. A brief comparison of the old facilities and the new is given below:

	OLD FACILITIES	PRESENT FACILITIES
1.	4th floor location	ground floor location
2.	no elevator	elevator adjacent to lab
3.	everything carried up stairs from and back down to parking lot	ground level unloating and access
4.	restrooms on other floors	restrooms next to lab
5.	minimal hot water availability	adequate hot water
6.	no adequate control of heat/AC	climate-controlled air
7.	small domestic chest freezers	large walk-in freezer
8.	2 fume hoods, unreliable exhaust	3 fume hoods & autopsy center
9.	departmental office 4 floors away	office nearby
10.	marginally adequate lighting	adequate lighting
11.	extensive insect problems	adequate insect control
12.	totally inadequate storage space	increased although still inadequate storage space
13.	inadequate fire protection	appropriate fire protection
14.	no accessibility for handicapped	handicapped accessibility
15.	old wooden storage shelves and cabinets	metal shelving and cabinets though still inadequate
16.	little computer capability	excellent computer hookups

The computerization of the 47 plus year old collections catalog is progressing well and should be available electronically to researchers country-wide by mid 1993.

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THE ROLL SITE (12-Cr-175): AN ABORIGINAL PETROGLYPH IN CRAWFORD COUNTY, INDIANA

Donald R. Cochran
Ball State University
Muncie, Indiana 47306
and
William R. Wepler
Indiana State Museum
Indianapolis, Indiana 46204

INTRODUCTION

To date, the Roll site contains the only verified aboriginal petroglyphs in Indiana (Swartz, 1985; Wellman, 1979). The site, located near Alton, Crawford County, Indiana, on Hoosier National Forest property, was discovered by Mr. Tom Roll during an outing on the Ohio River. Mr. Roll reported the site to the Indiana State Museum, and the site was recorded by the authors during July of 1988.

DESCRIPTION

The Roll site consists of nine glyphs (Figure 1) pecked into the surface of a large sandstone boulder that is immediately adjacent to the modern shoreline of the Ohio River. The boulder is located below a steep bluff on the outside margin of a large meander of the Ohio River and the location offers a clear view to the east, southeast, and south. The glyphs are being eroded by fluctuations in the river evel. The western end of the boulder is covered by soil and loose rocks and additional glyphs may yet be located at that end of the boulder.

The nine glyphs are arranged along the long axis of the boulder on a line that is generally 36° east of north. The visible portion of the sandstone boulder measures approximately 4 m long by 1.5 m wide. The glyphs are composed of irregular lines 10 cm to 15 cm wide and 1 cm to 5 cm deep. All lines are pecked. The glyphs are principally composed of curvilinear lines, but the three western glyphs incorporate relatively straight lines. Glyphs C and E in Figure 1 show the most damage from weathering.

A variety of methods were used to record the site. Initially, a sketch map was made showing the relative placement of each glyph. Rubbings were then made of each glyph was subsequently outlined in charcoal. Some weathered glyph, and photographs were taken. Due to poor reproduction by some of the rubbings, each glyph was subsequently outlined in charcoal. Some weathered glyphs were defined by reflecting sunlight with a compass mirror across the surface of the glyph. Following additional photography, each glyph was measured and mapped.

DISCUSSION

The glyphs recorded at the Roll site are of the Woodland Pit-and-Grove style most commonly found in the Tennessee Valley area of the Southeast, although the style also occurs at petroglyph sites in the Midwest (Wellman, 1979). Wellman

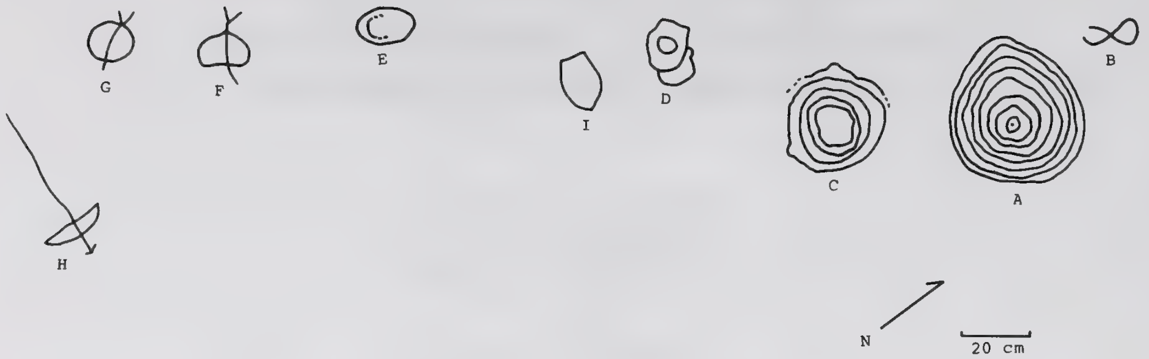

FIGURE 1. Arrangement of glyphs at the Roll site.

(1979) reports that the circle motif and its elaborations predominate among the elements in this style. Pit-and-Groove style petroglyphs have been interpreted as representing fertility symbols (Wellman, 1979), although other interpretations are possible.

Dating of the site is suggested by the bow and arrow glyph shown in Figure 1H. The glyph is similar to others reported from the Midwest and the Southeast (Wellman, 1979) and corroborates the proposed dating of A.D. 900-1750 for Midwestern and Southeastern petroglyph sites (Grant, 1967; Swauger, 1984; Wellman, 1979), since this span covers the range of bow and arrow use.

SUMMARY AND CONCLUSIONS

The Roll site represents the first verified aboriginal petroglyph site documented in Indiana. The site is related to petroglyph sites more common in the Tennessee Valley and may represent the northern boundary of the Woodland Pit-and-Groove style. Although interpretation of the site is currently unclear, its importance to the prehistory of the Ohio River drainage in Indiana is self evident.

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ARTIFICIAL CRANIAL DEFORMATION AND POROTIC HYPEROSTOSIS AT ANGEL SITE, VANDERBURGH COUNTY, INDIANA

Sherri L. Hilgeman
Glenn A. Black Laboratory of Archaeology
Indiana University
Bloomington, Indiana 45705

ABSTRACT: Artificial cranial deformation is the alteration of the natural morphology of the vault by cultural practices. Analysis of a sample of crania from the Late Prehistoric Angel site in southwestern Indiana shows that while the overall degree of deformation is slighter than that in other parts of the New World, it appears to be more prevalent at this site than at other sites studies in the Midwest. Markers of nutritional stress, *porotic hyperostosis* and *cribra orbitalia,* also seem to be correlated with the degree of artificial cranial deformation.

INTRODUCTION

Artificial cranial deformation is the alteration of the natural morphology of the vault by cultural practices. This may be an unintentional side effect of the restraint of an infant on a cradleboard or the result of an intentional effort to change the natural vault morphology to suit aesthetic ideals. According to Steward (1973), eastern North America was one of the three distinct areas of North America where artificial cranial deformation was practiced. Cranial deformation appears in the archaeological record in this area as early as the Adena phase, 200 BC to AD 400, in Kentucky and Ohio (Webb and Snow, 1945). Droessler (1981) provides an excellent summary of the cranial deformation literature and the cultural practices which may be involved in altering the natural vault morphology.

ANGEL SITE AND MATERIALS

A description and analysis of the artificial cranial deformation present in a subset of the burial population from the Angel Site, a Middle Mississippian (ca. AD 1200-1450) center on the lower Ohio River just upstream from the mouth of the Green River in Vanderburgh County, Indiana (Black, 1967) are presented in this paper. Aboriginally, this 40-hectare town was surrounded by a bastioned stockage, and within the stockage were located extensive habitation areas, substructure pyramidal mounds, and a plaza. Large-scale excavations were conducted during the WPA era (1939-1942) within a heavily utilized habitation area in the southeastern corner and on Mound F in the southwestern portion of the site. Much smaller areas were excavated elsewhere during the WPA era and later during a continuing series of Indiana University summer archaeological fieldschools. In all, less than four percent of the total site area has been excavated.

The crania examined were recovered during the large WPA excavations in the southeastern corner of the site and represent the bulk of the relatively complete crania. The 48 skulls listed by Johnson (1957, Tables 13 and 18) from

TABLE 1. Artificial cranial deformation at the Angel site.

Burial Cat. No.	Sex	Flattening Planes Fr[1]	Bf[1]	Lb[1]	Oc[1]	As[2]	Neumann's Classification	CO[3]	PH[3]
X11C/1910	F	—	—	S	—	—	lambdoid	*	M
X11C/1913	M	S	—	M	S	—	fronto-lambdoid	*	P
X11C/1919	F	—	—	M	—	—	lambdoid	*	—
X11C/1932	M	—	—	S	—	L	lambdoid	*	—
X11C/2213	F	—	M	M	S	—	bifronto-occipital	*	—
X11C/2214	M	—	—	—	—	L		—	—
X11B/1779	M	S	M	M	—	L	fronto-/bifronto-verticooccipital	*	—
M11B/3272	F	M	—	M	*	—	fronto-verticooccipital	*	—
X11B/3278	F	—	—	S	S	—	lambdoid/occipital	*	—
X11B/3284	F	—	—	S	—	—	lambdoid	P	—
X11B/3303	M	—	S	M	—	R	bifronto-lambdoid	—	—
W11A/1804	M	S	—	M	M	—	fronto-verticooccipital	*	P
W11A/3237	M	—	M	—	—	L	bifrontal	P	P
W11A/11302	M	M	—	—	M	—	fronto-verticooccipital	—	P
W11A/11857	M	M	M	M	*	—	fronto-/bifronto-verticooccipital	*	P
W11A/12814	M	M	—	M	—	—	fronto-verticooccipital	—	M
W11A/13678	M	M	—	M	M	—	fronto-verticooccipital	*	—
W11B/443	M	—	—	M	M	—	lambdoid/occipital	*	—
W11B/804	F	S	—	M	M	L	fronto-lambdoid	P	—
W11B/805	M	S	—	M	*	—	fronto-lambdoid	—	M
W10D/495	M	S	—	S	M	L	fronto-lambdoid	P	M
W10D/4483	F	S	—	S	M	—	fronto-verticooccipital	*	P
W10D/13132	F	M	—	M	S	—	fronto-verticooccipital	P	P
W10D/13185	F	M	—	M	S	—	fronto-verticooccipital	—	M
W10D/13594	F	—	S	S	—	—	bifronto-occipital	—	—

[1] Coding for flattening planes: **F**rontal to **O**ccipital.

—	absent
S	slight
M	marked
*	bone too fragmentary

[2] Coding for flattening planes: **As**terion.

—	absent
L	present on left side
R	present on right side

[3] Coding for **C**ribra **O**rbitalia and **P**orotic **H**yperostosis.

—	absent
P	present
M	marginally present
*	orbital surface of frontal not preserved

Subdivisions X-11-C, X-11-B, X-10-C, W-11-A, W-11-B, and W-10-D provided a maximum list of potential specimens. Of these, three could not be located in the curated collections. Twenty were sufficiently fragmentary and/or distorted postmortem so that extensive reconstruction would be necessary, resulting in a greater chance of falsely identifying deformation. The final sample studied consisted of 25 crania, 14 male and 11 female.

CRANIAL DEFORMATION

The scoring of deformation used for the Angel series was adapted from that of Judith Droessler (1981), which was in turn modified from the classificatory scheme of Georg Neumann (1942). Of the seven types of artificial cranial deformation described by Neumann, four are relevant to the study of the Angel cranial deformation (Figure 1).

According to Neumann (1942, pp. 308), *lambdoid deformation* (Figure 1A) "occurs only in a mild form as an occasional individual variation in crania with simple occipital deformation in series from the southeastern states. In skulls from the Chaco Canyon region of New Mexico, . . . the plane of flattening is inclined at an angle of 50 to 60 degrees to the eye-ear plane [Frankfurt horizontal]." Neumann distinguishes this from natural lambdoid flattening; the latter is centered on the sagittal suture between the centers of artificial obelionic and lambdoid deformation.

Occipital deformation (Figure 1C) is "at right angles to the eye-ear plane, is probably unintentional, often markedly asymmetrical, and generally does not involve the frontal bone" (1942, pp. 308). This type of flattening is sometimes referred to as *cradleboard deformity* (Droessler, 1981); the flattening is thought to have been the result of the weight of the infant's head on a hard cradleboard (Tennessee State Museum, 1985). This may be the reason Neumann characterized it as probably unintentional.

Bifronto-occipital deformation (Figure 1B) "consists of bilateral flattening that produces a very narrow frontal bone associated with a moderate degree of vertical occipital flattening" (Neumann, 1942, pp. 308). *Fronto-verticooccipital deformation* (Figure 1D) "is characterized by flattening of the frontal, probably by means of a board, in conjunction with the simple vertical occipital deformation produced by tying the head of the infant to a flat surface" (Neumann 1942, pp. 309). Since Neumann considered lambdoid deformation a variation of occipital deformation, his compound categories of bifronto-occipital and fronto-verticooccipital deformation could and probably did include *bifronto-lambdoid* and *fronto-lambdoid deformation*, respectively.

Because anterior flattening was not clearly associated with posterior flattening in the Illinois Late Woodland and Mississippian cranial series examined by Droessler (1981), she did not use Neumann's types but derived from them four planes of cranial flattening: *frontal*, *bifrontal*, *lambdoid* (centered at *lambdoid*, the point at which the two parietal and the occipital bones meet), and *occipital* (centered at *inion*, the point at the base of the external occipital protuberance in the midline of the skull). These four planes of cranial flattening could be independently scored.

The flattening in the Angel sample was scored with reference to the skulls Droessler considered typical of the deformation classes she created (Droessler,

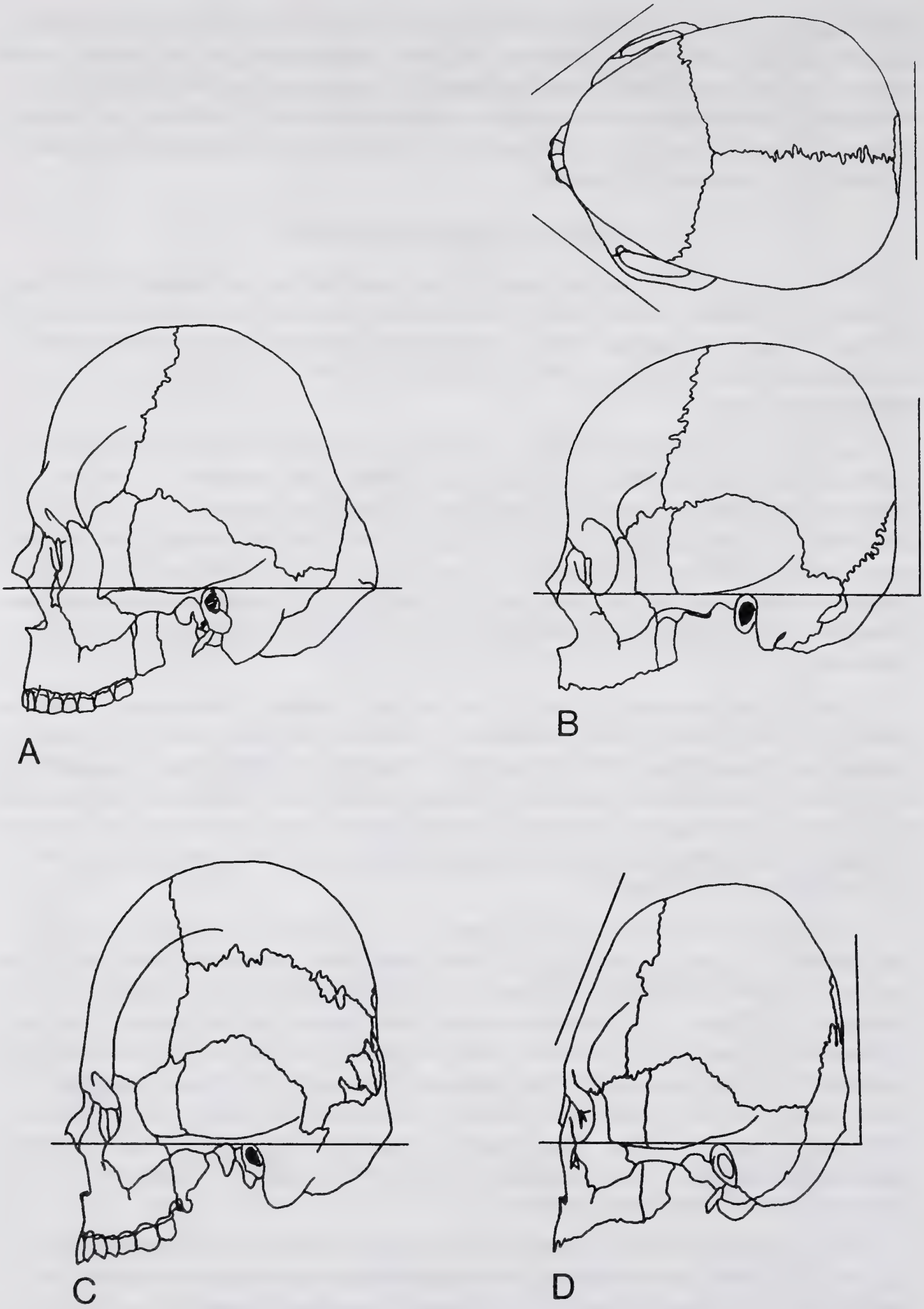

FIGURE 1. Four of Neumann's types of artificial cranial deformation: **A.** lambdoid; **B.** bifronto-occipital; **C.** occipital; and **D.** fronto-verticooccipital (adapted from Neumann, 1942, p. 307).

TABLE 2. Incidence of deformation of by plane of flattening and sex of individuals.

	Frontal	Bifrontal	Lambdoid	Occipital	Asterion	
MALES	9	4	11	6	6	Count
(no = 14)	(64.3)	(28.6)	(78.6)	(42.8)	(42.8)	(%)
FEMALES	4	2	11	6	1	Count
(no = 11)	(36.4)	(18.2)	(100.0)	(54.5)	(9.1)	(%)
TOTAL	13	6	22	12	7	Count
	(52.0)	(24.0)	(88.0)	(48.0)	(28.0)	(%)

1981, Table 10). For each of the four flattening planes, the crania from Angel were arranged in a continuum from no flattening to most flattened. This continuum was then collapsed into three groups: no flattening, slight flattening, and marked flattening. Approximately two weeks later, the scoring was repeated. Seventy-six percent of the flattening planes were assigned to the same rank in the second scoring as in the first. About one-half of the discrepancies involved difficulties in separating the lambdoid and occipital flattening planes.

While scoring the four more conventional kinds of flattening, a fifth asymmetrical plane of flattening, centered at *asterion* (the point at which the occipital, parietal, and temporal bones meet) and which could not be attributed to premature suture closure or post-mortem warping, was noted on seven skulls. Neumann (1942) suggested that occipital deformation could be markedly asymmetrical, and asterion flattening could be an illustration of this asymmetry. Due to its infrequency and ambiguous importance, it was scored present or absent, and the side on which it occurred was noted.

DISCUSSION

Table 1 presents the data collected on artificial cranial deformation within the Angel sample. Both classifications (Neumann's, as expanded here, as well as the independent scoring of flattening planes) are given. The following types of deformation, in Neumann's terms, were observed: lambdoid deformation (no. = 4), bifronto-occipital deformation (no. = 2), fronto-verticooccipital deformation (no. = 8), bifronto-lambdoid deformation (no. = 1), and fronto-lambdoid deformation (no. = 4). Five skulls exhibited patterns of cranial deformation which did not fit neatly within Neumann's classification. Only one skull did not exhibit any form of deformation. However, while deformation was the rule within the Angel series, it was much more subtle than that present in South American, Northwest Coast, or Southwestern U.S. series (Shipman, *et al.*, 1985, Figure 16-4; Flower, 1881).

Table 2 summarizes the incidence of the five planes of flattening observed within the Angel series. For the four conventional planes of flattening, the occurrence of deformation appears more frequent at Angel, when compared to Droessler's (1981) results from the Schild and Yokem Mississippian series. At Angel, lambdoid flattening occurs most frequently; 88% of the crania exhibited this type of flattening. This is slightly higher than the incidence at both Schild (81.4%) and Yokem (74.4%) but seems comparable. Fifty-two percent of the Angel crania exhibited frontal flattening; this also appears to be more frequent than at Schild

(36.1%) and Yokem (10.0). Occipital flattening is present on 48.0% of the Angel crania, and this would rise to 64.0% if asterion flattening is an asymmetrical variant of occipital flattening. This value is quite high, when compared to Schild (12.5%) and Yokem (10.0%). Twenty-four percent of the Angel skulls exhibited bifrontal flattening. This seems roughly comparable to Schild (19.4%), and both are high, when compared to Yokem (7.5%). Finally, flattening at asterion appears to occur preferentially on the left side.

The chi-square statistic was calculated for the frequencies represented by the percentages just enumerated. At a 95% confidence level for a one-tailed test with 6 degrees of freedom, the null hypothesis was rejected, and it was concluded that there is a significantly greater frequency of cranial deformation at Angel than at Schild and Yokem.

At least part of this difference may be explained in terms of the relative positions of the sites being compared in their respective settlement hierarchies and, by extension, the sites' inhabitants in their respective socio-political hierarchies. Angel was the "capital" of a relatively small, peripheral Mississippian polity, and the individuals buried there should include the highest ranking persons in the socio-political hierarchy. In contrast, the Schild and Yokem cemeteries served hamlet and farmstead residents in the hinterlands of the much larger Cahokia polity (Cook, 1983; Goldstein, 1980; Perino, 1971a, 1971b). Thus, the individuals buried at Schild and Yokem should have been of relatively lower status than those buried at Angel. Additionally, Cook (1983) has suggested that some portion of the Schild burial population, especially adult males, was buried or processed elsewhere, possibly at Cahokia. If, as Harn (1971) has suggested for the Dickson Mounds Mississippian burial population, artificial cranial deformation is indicative of high socio-political status, then it is not unexpected that the residents of Angel should show greater frequencies of artificial cranial deformation than the individuals residing in the vicinity of the Schild and Yokem cemeteries.

CRANIAL DEFORMATION AND POROTIC HYPEROSTOSIS

No systematic attempts were made to identify all paleopathologies during this study. However, while examining the crania during scoring of the deformation, a number of crania were noted that exhibited *porotic hyperostosis* and/or *cribra orbitalia*. These conditions appeared to be most prevalent on crania with the most extreme frontal and lambdoid/occipital flattening (D.C. Cook, personal comm.).

Porotic hyperostosis (also referred to as *hyperostosis symmetrica* and *osteoporosis symmetrica*) and *cribra orbitalia* are lesions of the cranium, which are non-specific indicators of anemias (Cook, 1984). The combination of the widening of the spongy diploe and the thinning of the outer dense cortical bone results in a porous-appearing exterior. Cribra orbitalia is the formation of porous bone on the orbital surface of the frontal bone (Shipman, *et al.*, 1985, Figure 16-9), and porotic hyperostosis occurs on the external surfaces of the frontal, parietal, and occipital bones. Observation of cribra orbitalia on the Angel crania was limited, because in many cases the orbital surfaces of the frontal were not preserved. The incidence of porotic hyperostosis was observed on the parietal behind and above the point of the bosses and on the occipital around and above the external occipital protuberance.

Posterior Flattening	Anterior Flattening: absent	slight	marked
absent	o		x
slight	o x o x	o	
marked	o o	x x o x x x x	o x x o o x x o x

Porotic Hyperostosis / Cribra Orbitalia

x - present
o - absent

TABLE 3. Occurrence of porotic hyperostosis/cribra orbitalia by varying degrees of anterior and posterior artificial cranial flattening.

In general, these conditions have been attributed to a number of anemias: thalassemia, hereditary anemia, sickle-cell anemia, and iron-deficiency anemia. The alteration of the cranial bones is the result of the increased red blood cell production taking place in the diploe. The incidence of porotic hyperostosis/cribra orbitalia in New World populations is usually attributed to nutritional stress (Goodman, *et al.*, 1984). Roosevelt (1984) has suggested that porotic hyperostosis/cribra orbitalia indicates chronic iron-deficiency anemia, which may result from high carrying-capacity (maize) diets that are often low in iron. Goodman, Lallo, Armelagos, and Rose (1984) have documented an increase in the incidence of porotic hyperostosis/cribra orbitalia from the Late Woodland to the Mississippian periods populations at Dickson Mounds in Illinois. During the Late Woodland period, porosity is limited to the orbits, but by the Mississippian period, porosity has involved other cranial bones, suggesting an increasing nutritional stress. They hypothesize that the frequency and degree of involvement of porotic hyperostosis increases with increased maize agriculture.

The incidence of cribra orbitalia and porotic hyperostosis is tabulated in Table 1, and an attempt to illustrate the occurrence of both markers by degree of anterior (frontal and bifrontal) and posterior (lambdoid and occipital) flattening is presented in Table 3. It appears that porotic hyperostosis/cribra orbitalia, hence anemia, is positively correlated with marked posterior and slight-to-marked anterior cranial deformation.

This result seems counterintuitive. If artificial cranial deformation is indeed a status marker, then one would expect that the most deformed skulls would be the least likely to exhibit signs of nutritional stress, if higher status individuals had access to a "better" quality (meaning more meat and less maize) diet. However, this dietary pattern may not be the situation, or this conclusion may be too simplistic. When these individuals were alive the entire population may have been under some type of stress, nutritional or otherwise, that was manifested in part by anemia. In addition, cranial deformation may not be simply a status marker but a marker of some other role, such as clan or society membership. Finally, it seems reasonable to assert that the conditions subsumed under the simple equation "cranial deformation = higher status = better quality diet" are actually much more complex. Hopefully, further work on the Angel and similar burial populations will help clarify the picture.

ACKNOWLEDGMENTS

I would like to thank Dr. Mark R. Schurr for bringing the artificial cranial deformation within the Angel Site skeletal series to my attention, Dr. Della Collins Cook for her assistance in scoring the cranial deformation and pointing out the markers of nutritional stress, and Dr. Christopher S. Peebles for permission to study the skeletal material.

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THE ASHER BRANCH FISH WEIR, 12-MI-320

William R. Wepler
Indiana State Museum
Department of Natural Resources
Indianapolis, Indiana 46204
and
Donald R. Cochran
Archaeological Resources Management Service,
Ball State University
Muncie, Indiana 47306

INTRODUCTION

Oral history and low water levels on the Wabash River led to the documentation of the Asher Branch fish weir, 12-Mi-320. The weir's cultural affiliation and period of use are unknown. A description, possible origins, and potential use of the site for harvesting a predictable food resource will be the focus of this paper.

LOCATION

The Asher Branch fish weir is located in the NE$^1/_4$ of the SE$^1/_4$ of the NE$^1/_4$ of Section 28, Township 27 North, Range 5 East (USGS 7$^1/_2$′ map, Richvalley Quadrangle) in Miami County. Located on the upriver end of a large shallow area, the weir spans the Wabash River about 500 feet east (upstream) of the mouth of Asher Branch.

Dr. Stewart Rafert brought the weir to the attention of the Indiana State Museum during the summer drought of 1988. He knew of the weir's location through Lamoine Marks, a Miami Indian. Marks, in his eighties, learned of the weir as a child, when his father pointed out the location while fishing nearby. The weir is known to the Miami as "an old Indian Dam." Oral tradition states that the Miami never used the weir and that its construction was by other Native Americans.

DESCRIPTION

Archaeological Resources Management Service and the Indiana State Museum carried out a preliminary survey of the Asher Branch site in the summer of 1988. Field work focused on recording the location and size of larger, more prominent rocks within the weir. The survey resulted in a map of the site (Figure 1) and many photographs and slides documenting its current condition.

The weir, consisting of about 52 m of dam, measures 45.5 m between its northern and southern ends. The center of the weir forms a "V" with its apex pointing upstream. The apex opening is 1.75 m wide. Dam height varies between 17.5 and 52 cm above the river bed. The southern most 3 m of the dam turns upstream and towards the river bank.

Stones of various shapes and sizes were piled, stacked, or wedged in place to construct the dam. In some instances, flat stones, thin in cross section, are placed on edge. The width of the dam varies depending on the size and number of stones

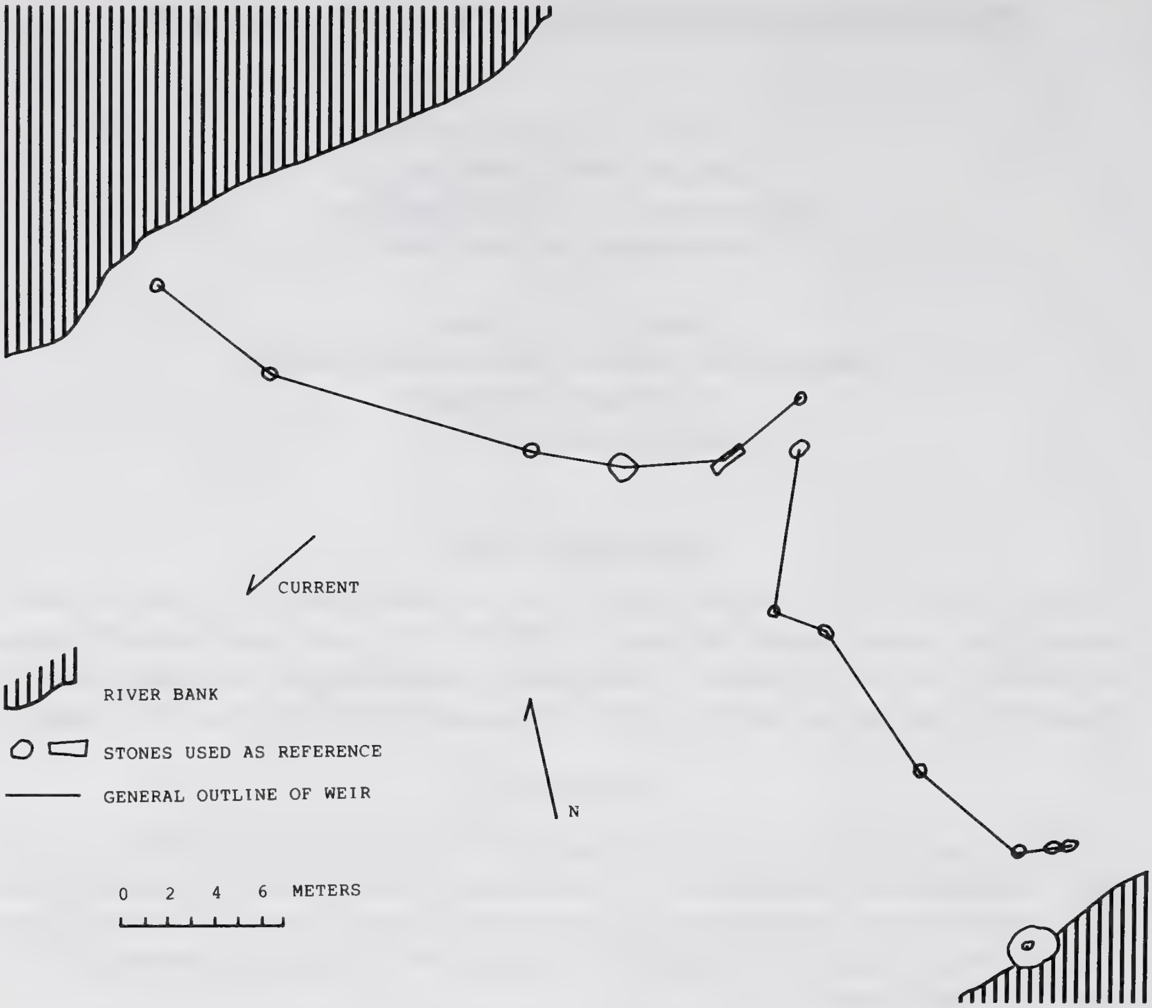

FIGURE 1. Schematic drawing of the Asher Branch Fish Weir, 12-Mi-320. Scale in meters.

used. The irregular outline of the weir and the size of some of the stones suggest that the weir's builders took advantage of larger rocks already at or near their original location.

The weir's layout suggests two primary fishing stations. The first is the apex of the V in the center of the weir. The second is where the wall bends upstream forming a narrow passage betweeen the weir and the southern river bank. Field work found no evidence of traps in either location.

DISCUSSION

Miami oral tradition says that the weir is of Native American construction and that it predates the Miami's extensive use of the Upper Wabash. This suggests a precontact or protohistoric date for the weir's construction. Native American groups that inhabited Indiana historically and used fish weirs include the Potawatomie, Sauk, Fox, (Rostlund, 1952,) and Delaware (Rostlund, 1952; Weslager, 1972). However, the authors found no ethnohistoric data supporting the use of weirs in Indiana by Native Americans.

Site files at the archaeology laboratory, Ball State University, indicate that the General Land Office (GLO) recorded two "fish traps" in 1821, along a stretch of the White River heavily used by the Delaware. The same survey recorded five

Delaware villages in Madison and Delaware counties as well as some Euro-American settlers in the general area. (Use of the term "trap" could refer to a weir, a weir/trap combination, or a trap with no weir.)

These traps are located about one mile apart on either side of the Madison/Hamilton County line. The authors saw the remains of the Madison County trap, which is constructed from wood and not stone. These traps do not conform to those described as built by the Delaware elsewhere (Weslager, 1972; Zeisberer, 1885) and may have been built by early settlers.

The Asher Branch weir is dissimilar to the traps in the White River. It is also unlike the weirs of prehistoric construction reported from Kentucky and Tennessee (Funkhauser and Webb, 1932; Myer, 1928). Nor is it similar to the 19th and early 20th century weirs reported from Tennessee (Cobb, 1978; McCoy, 1980).

"All weirs are alike but no two are the same" (Rostlund, 1952, p. 102). The function of a weir is to obstruct or channel the passage of fish to aid in their capture. Fish pass through the weir by their natural movements or are herded through the weir by part of the fishing group. Capturing is by trapping, spearing, and netting. Passive and active methods of fishing are defined on the basis of how fish approach the weir.

Active fishing requires some individuals to herd or drive the fish to and through the weir while others wait to capture the fish. It is most effective when there are concentrations of fish in the shallows near the weir. Active fishing requires the involvement of several individuals.

Passive fishing relies on natural movement of the fish through the weir. This allows the fisherman to trap fish and collect them at leisure or to take them by spearing or netting as they pass by. Passive use of a weir is an individual or group effort.

Asher Branch weir can function in an active or passive manner. Active fishing is most efficient when fish are abundant in the shallow waters below the weir. Passive fishing is most efficient while fish are moving upstream in large numbers. In either case, concentrations of fish in the shallows or the movement of large numbers of fish occur in response to the natural life cycles of specific species.

Species taken at the Asher Branch weir probably included buffalo fish and suckers (family Catostomidae), which seasonally move upstream and gather in shallow areas. They are abundant, palatable, and catchable by either active or passive means. Sixteen species have occurred historically in Indiana (Blatchley, 1938). Golden redhorse (*Moxostoma erythrurum*) and the common white sucker (*Catostomus commersoni*) are particularly abundant in rivers (Gammon and Gerking, 1966). Although catostomids have many small bones, most are accepted as "well flavored" (Blatchley, 1938).

In the fall (typically November), many members of the sucker family concentrate in the deeper pools of rivers, where they remain throughout the winter. When water temperature rises in the spring (typically April and May), the suckers move upstream, gathering in shallows to spawn. Blatchley (1938, p. 40) described the spring sucker run as follows:

> Sixty years ago this Red Horse was much more common on its spring run than now, so much so that I sometimes let a snare down in the

> rapid water of an old mill race where I could not see the fish, dragged it slowly, a short distance down stream, then jerked, and about three times out of seven brought up a fish. . . . In the early days, the spring run of these suckers never failed to attract the attention of the settlers and large numbers of them were salted down or put in brine for winter use.

The natural movement of suckers through the mill race described by Blatchley is not unlike the channeling of fish by a weir. This suggests that the sucker run could have provided ample natural movement of fish through the weir to allow for passive capture while the run was in progress. The congregation of spawning suckers in the shallows near the weir provides an opportunity for active capture. Suckers taken during spawning season have the added advantage of the eggs (roe) which are regarded by many as a delicacy (Gammon and Gerking, 1966).

The weir's construction shows that the fish sought were moving up stream, either by natural movement or by herding. The weir's loack of height and slight build might favor the casualness of natural movement over the frenzied fleeing of fish associated with herding. These same factors suggest short term, seasonal use, as opposed to constant use over a long period.

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Dr. Stewart Rafert and Mr. Lamoine Marks brought the weir to our attention and shared with us Miami oral history. Amy Johnson, Lisa Maust, and Blake Cochran worked on the field crew. John Wyatt produced Figure 1.

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BOTANY

Chair: Phillip Marshall
Vallonia State Tree Nursery
Vallonia, Indiana 47281

Chair-Elect: Charles T. Hammond
Department of Biology
St. Meinrad College
St. Meinrad, Indiana 47577

ABSTRACTS

Propagation and Maintenance of High Density, Disease-Free Orchid Plantlets in Species Banks. Herbert L. Saxon, Wheeler Orchid Collection, Biology Dept., Ball State University, Muncie, Indiana 47306.———The habitat of tropical epiphytes is disappearing. Emerging industrial societies will probably continue to deforest the tropics into the next century. Species banks will be essential gene pools of plant species which will require reintroduction into sanctuaries as they become extinct in the wild. The orchids are the largest plant family among tropical epiphytes and the Wheeler Orchid Collection and Species Bank (WOCSB) is one of the most diverse collections of orchids in the world. Research at WOCSB emphasizes developing a high copy number, disease-free pool of plantlets which can be held in minimum space or *in vitro* in distributable condition. The speaker will show evidence that: orchid plantlets can be held *in vitro* for longer than one blooming and new seed production cycle; the rate of viral infestation of old orchid collections held by traditional methods necessitates extended flasked time in species banks; and that plantlets thus propagated can be matured in a high-density, compost free culture.

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THE EFFECT OF ELECTRON DONORS ON TRANSMEMBRANE FERRICYANIDE REDUCTION AND ASSOCIATED PROTON EXCRETION BY CULTURED CARROT CELLS

Rita Barr, Mary Frischkorn, Michael Green, and Frederick L. Crane
Department of Biological Sciences
Purdue University
West Lafayette, Indiana 47907

INTRODUCTION

The natural electron donor to transplasma membrane electron transport with impermable potassium ferricyanide as the electron acceptor can either be NADH (Barr, 1987, 1988; Barr, *et al.*, 1987; Böttger and Lüthen, 1986; Böttger, *et al.*, 1985; Bown and Crawford, 1988; Bown, *et al.*, 1988; Craig and Crane, 1981; Federico and Giartosio, 1983; Ivankina and Novak, 1980; Krüger and Böttger, 1988; Neufeld and Bown, 1987) or NADPH (Cakmak and Marschner, 1988; Lass, *et al.*, 1986; E. Marré, *et al.*, 1988; M.T. Marré, *et al.*, 1988; Rubinstein, *et al.*, 1984; Sijmons, *et al.*, 1984a, 1984b; Ze-sheng, *et al.*, 1984). Since either nucleotide is impermeable to living cells, since there is a NADH oxidase on the outside of cells that is stimulated by plant hormones (Brighman, *et al.*, 1988) or not (de Luca, *et al.*, 1984; Lin, 1982, 1984; Pupillo, *et al.*, 1986), and since NADH can chemically reduce ferricyanide, a new procedure for studying electron donor effects on cultured carrot cells was devised. It consisted of preloading these cells with electron donors for 15, 30, 45, or 60 min and washing any non-internalized donor off before assaying ferricyanide reduction and associated H^+ excretion. Such a procedure yielded good results with differences among electron donors.

MATERIALS AND METHODS

Carrot cells were grown in 250 ml Erlenmeyer flasks on 50 mls of culture medium as previously described (Barr, 1987). TRansmembrance ferricyanide reduction and H^+ excretion assays were also performed as described therein.

Incubation of cells with four electron donors—NADH, sodium ascorbate, H_2O_2, and $MnCl_2$—was as follows: 5 ml aliquots of washed carrot cells suspended in sucrose-salts solution (0.1 M sucrose, 10 mM KC1, 10 mM NaC1 and 10 mM $CaC1_2$) were transferred to 15 ml centrifuge tubes and the required concentrations of electron donors were added. The tubes were mixed briefly on a Vortex and incubated for 15, 30, 45, an 60 min on a reciprocal shaker. Two min before the end of each incubation period, the tubes were filled with an additional 10 ml of sucrose-salts solution, mixed by stirring with a spatula, and centrifuged for 2 min in a table model International centriguge at 1,500 RPM (about 200 x g) at room temperature. After centrifugation, the supernatant was discarded, and the cells were suspended in 5 ml of fresh sucrose-salts. Aliquots (0.1 ml) of these cells were used for simultaneous ferricyanide reduction and H^+ excretion assays. With practice, a single experiment with four separate incubation times could be conducted in 60 ± 10 min. However, in this study, each donor was used in three different concentrations, although only the significant data are reported here.

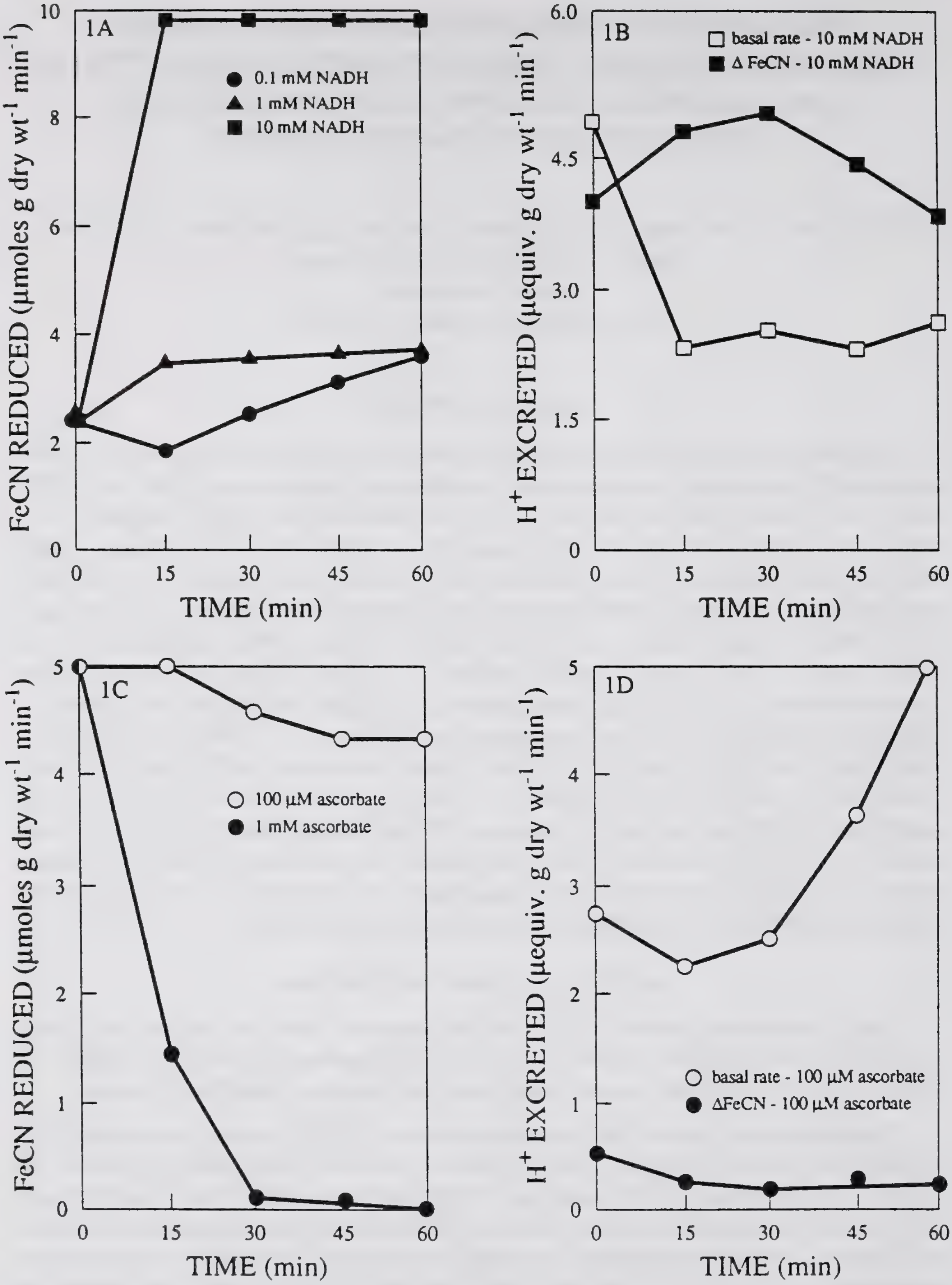

FIGURE 1. The effect of electron donors on transmembrane redox reactions and associated proton excretion by cultured carrot cells. **A.** The effect of NADH on ferricyanide reduction. **B.** The effect of NADH on H^+ excretion. **C.** The effect of sodium ascorbate on ferricyanide reduction. **D.** The effect of sodium ascorbate on H^+ excretion. Carrot cells were preloaded with electron donors. Excess donor was washed off after 15, 30, 45, or 60 min before assays for ferricyanide reduction or H^+ excretion. Assays are described in **Materials and Methods.**

RESULTS AND DISCUSSION

Transmembrane redox reactions involve electron donation to the electron transport chain by internal electron donors, NADH (Barr, 1987, 1988; Barr, *et al.*, 1987; Böttger and Lüthen, 1986; Böttger, *et al.*, 1985; Bown and Crawford, 1988; Bown, *et al.*, 1988; Craig and Crane, 1981; Federico and Giartosio, 1983; Ivankina and Novak, 1980; Krüger and Böttger, 1988; Neufeld and Bown, 1987) or NADPH (Cakmak and Marschner, 1988; Lass, *et al.*, 1986; E. Marré, *et al.*, 1988; M.T. Marré, *et al.*, 1988; Rubinstein, *et al.*, 1984; Sijmons, *et al.*, 1984a, 1984b; Ze-sheng, *et al.*, 1984). Both nucleotides are impermeable to plant plasma membrances, so that exogenous NADH can only activate an outside NADH oxidase (de Luca, *et al.*, 1984; Lin, 1982, 1984; Pupillo, 1986), which leads to stimulation of ferricyanide reduction andassociated H^+ excretion by cultured carrot cells (Figures 1A and B). Sodium ascorbate, a presumed permeable electron donor to whole cells, in a low concentration (100 μM), slightly inhibited ferricyanide reduction and associated H^+ excretion, while the basal rate of H^+ excretion due to the action of the plasma membrane H^+-ATPase was stimulated (Figures 1C and D). Hydrogen peroxide, another permeable electron donor, stimulated ferricyanide reduction (Figure 2A), but inhibited H^+ excretion in presence of ferricyanide (Figure 2B). Proton excretion by the H^+-ATPase was slightly stimulated by hydrogen peroxide. This result is unexpected by a model of tight coupling between transmembrane ferricyanide reduction and associated H^+ excretion, but the relationship between these two processes is, probably, more complicated than a simple 1:1 relationship. A controversy still exists in the plant plasma membrane literature on this point. Originally, a tight coupling between ferricyanide reduction and H^+ excretion was suggested (Barr, 1987, 1988; Barr, *et al.*, 1987; Böttger and Lüthen, 1986; Böttger, *et al.*, 1985; Bown and Crawford, 1988; Bown, *et al.*, 1988; Craig and Crane, 1981; Federico and Giartosio, 1983; Ivankina and Novak, 1980; Neufeld and Bown, 1987), but lately various studies have shown (Lass, *et al.*, 1986; E. Marré, *et al.*, 1988; M. Marré, *et al.*, 1988; Rubinstein, *et al.*, 1984; Ze-sheng, *et al.*, 1984) that a more indirect relationship may exist in some cases, where only electrons cross the plasma membrane, but the H^+ liberated upon oxidation of NADH inside the cell may be deposited in a special membrane domain from which the H^+-ATPase is activated by plasma membrane redox protons (Morré, *et al.*, 1986). Manganous chloride used as an electron donor to plasma membrane redox inhibited both ferricyanide reduction (Figure 2C) and redox-associated H^+ excretion in a concentration of 1 mM (Figure 2D); this concentration also inhibited 75% of the H^+-ATPase excreted protons (Figure 2D). Thus, various electron donors, preincubated with carrot cells for 15, 30, 45, and 60 min and washed off before assays, evoked different responses from cells: (1) stimulation of both ferricyanide reduction and associated H^+ excretion (NADH); (2) inhibition of redox and redox-associated H^+ excretion, while stimulating the basal rate of H^+ excretion by the plasma membrane H^+-ATPase (ascorbate); (3) stimulation of ferricyanide reduction, but inhibition of redox H^+ excretion, while stimulating H^+-ATPase-mediated protons (hydrogen peroxide); and (4) inhibition of ferricyanide reduction and H^+ excretion by redox reactions and H^+-ATPase (manganous chloride). The above results show that the relationship between transmembrane redox and associated H^+ excretion in relation to the action of the plasma membrane H^+-ATPase is not a simple one.

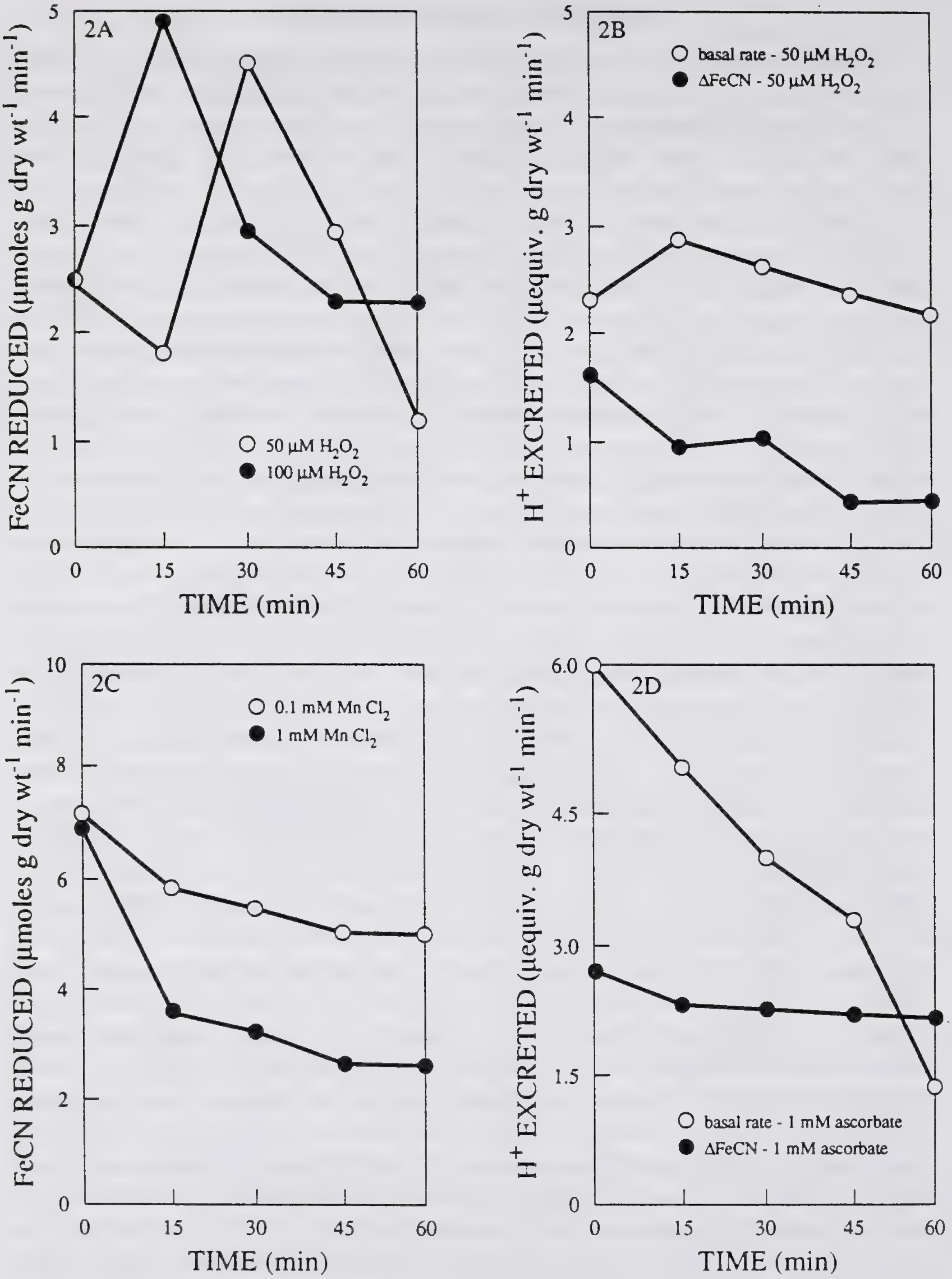

FIGURE 2. The effect of electron donors on transmembrane redox reactions and associated proton excretion by cultured carrot cells. **A.** The effect of H_2O_2 on ferricyanide reduction. **B.** The effect of H_2O_2 on H^+ excretion. **C.** The effect of $MnCl_2$ on ferricyanide reduction. **D.** The effect of $MnCl_2$ on H^+ excretion. Carrot cells were preloaded with electron donors. Excess donor was washed off after 15, 30, 45, or 60 min before assays for ferricyanide reduction or H^+ excretion. Assays are described in **Materials and Methods.**

ACKNOWLEDGMENTS

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SPORANGIOSPORE VARIABILITY IN *PILOBOLUS*

K. Michael Foos and Brenda S. Jeffries
Department of Biology
Indiana University East
Richmond, Indiana 47374

INTRODUCTION

Sporangiospore size and shape are taxonomic characteristics given for all species of *Pilobolus* (Grove, 1934; Zycha, *et al.*, 1969). To be of taxonomic value, spore size and shape must remain consistent. While it is widely held that these characteristics are consistent, no records exist in the literature to indicate that this is the case over time and through subsequent transfers. Recently, variability was observed in spore size and shape during the first few days after transfer, suggesting that these characteristics might be of questionable taxonomic usefulness. This project was designed to determine if sporangiospore size and shape remain consistent enough over time and through subsequent transfers to justify their use as dependable taxonomic characteristics.

METHODS AND MATERIALS

Two isolates of *Pilobolus* were recovered from domestic animals in Fayette County, Indiana, using the technique of Foos and Royer (1986). *Pilobolus longipes* was recovered from horse feces and *P. crystallinus* from cow feces. Single sporangia, collected from the original fecal samples, were transferred to microscope slides in a drop of sterile distilled water and carefully disarticulated using a sterile probe. Spores from these sporangia were examined with a brightfield microscope and then transferred to petri dishes containing dung agar to provide cultures for subsequent transfers through several sporulation cycles. All cultures were maintained on dung agar at room temperature (20°C) under cool white fluorescent lights with an intensity of 2000 lx and 12 hr alternating light and dark periods.

Two methods of successive transfers were compared. In one set of experiments, sporangia produced on cultures were collected and transferred to petri dishes containing fresh media. In the second set of experiments, cores of agar containing hyphal tips were cut from the growing mycelia with a sterile 8 mm cork bore and transferred to petri dishes containing fresh media.

From each subsequent culture, sporangia containing sporangiospores were collected daily for the first four days after the initiation of sporulation. These sporangia were mounted in lactophenol on microscope slides and examined with a 1000X brightfield microscope. Spore dimensions of 50 sporangiospores per sporangium were measured and recorded. This procedure was repeated after each subsequent transfer for 6 or 11 transfers. Spore size measurements were compared and data analyzed using Minitab statistical software.

RESULTS

Sporangiospores of *P. longipes* had an overall mean length of 11.0 ± 0.8 μm and an overall mean width of 10.2 ± 0.8 μm. The mean dimensions of the spores found growing on the original cultures collected from dung were 12.5 ± 0.3 by

TABLE 1. Dimensions (μm) and length to width ratios of sporangiospores of *P. longipes* and *P. crystallinus* collected daily for the first four days after the initiation of sporulation.

		P. longipes			***P. crystallinus***	
Day	**Length**	**Width**	**Ratio**	**Length**	**Width**	**Ratio**
1	11.0 ± 0.7[a]	10.2 ± 0.7	1.08	9.1 ± 0.9	5.0 ± 0.5	1.55
2	10.7 ± 0.9	9.8 ± 0.9	1.08	9.4 ± 0.4	6.0 ± 0.3	1.55
3	10.9 ± 0.7	10.0 ± 0.6	1.09	9.1 ± 0.5	5.8 ± 0.3	1.57
4	11.0 ± 1.0	10.2 ± 0.9	1.08	9.3 ± 0.4	6.0 ± 0.4	1.54

[a] Standard deviation

11.5 ± 0.4 μm, while those from cultures produced by sporangia transferred to dung agar had mean dimensions of 10.6 ± 0.6 by 10.0 ± 0.6 μm, and those from cultures produced by hyphal tips transferred to dung agar had mean dimensions of 11.2 ± 0.9 by 10.4 ± 1.0 μm. Sporangiospores of *P. crystallinus* had an overall mean length of 9.3 ± 0.6 μm and an overall mean width of 5.9 ± 0.5 μm. The mean dimensions of the spores found growing on the original cultures collected from dung were 10.4 ± 0.5 by 7.2 ± 0.6 μm, while those from cultures produced by sporangia transferred to dung agar had mean dimensions of 9.3 ± 0.4 by 5.9 ± 0.5 μm, and those from cultures produced by hyphal tips transferred to dung agar had mean dimensions of 9.0 ± 0.4 by 5.9 ± 0.5 μm. Dimensions of sporangiospores produced during the first four days after the initiation of sporulation and those produced after different numbers of transfers are given in Tables 1 and 2.

Sporangiospore shape can be quantified by determining the length to width ratio of the spores. The overall mean length to width ratio of *P. longipes* spores was 1.08 ± 0.04. The mean length to width ratio of the original spores found growing on dung was 1.08 ± 0.02. Cultures growing on dung agar transferred by sporangia had a mean length to width ratio of 1.06 ± 0.03, while those growing on dung agar from hyphal tip transfers had a mean length to width ratio of 1.10 ± 0.04. *Pilobolus crystallinus* had an overall mean length to width ratio of 1.54

TABLE 2. Dimensions (μm) and length to width ratios of sporangiospores of *P. longipes* and *P. crystallinus* produced after each transfer.

		P. longipes			***P. crystallinus***	
Tr[a]	**Length**	**Width**	**Ratio**	**Length**	**Width**	**Ratio**
1	10.7 ± 0.5[b]	9.8 ± 0.3	1.09	9.7 ± 0.2	6.0 ± 0.8	1.61
2	10.4 ± 0.6	9.7 ± 0.6	1.07	9.6 ± 0.2	5.8 ± 0.5	1.65
3	10.5 ± 0.3	9.6 ± 0.6	1.09	9.3 ± 0.4	6.1 ± 0.3	1.52
4	11.3 ± 0.9	10.4 ± 0.8	1.09	9.4 ± 0.5	6.4 ± 0.4	1.48
5	10.7 ± 0.6	9.8 ± 0.6	1.09	8.9 ± 0.6	5.9 ± 0.4	1.51
6	11.4 ± 0.8	10.7 ± 0.8	1.07	9.1 ± 0.8	5.7 ± 0.6	1.61
7				9.0 ± 0.8	5.7 ± 0.3	1.56
8				8.9 ± 0.9	5.7 ± 0.4	1.58
9				8.9 ± 0.8	5.8 ± 0.2	1.53
10				9.4 ± 0.8	5.8 ± 0.2	1.62
11				8.7 ± 0.4	6.0 ± 0.3	1.46

[a] Number of transfers
[b] Standard deviation

± 0.15. The mean length to width ratio of the original spores found growing on dung was 1.45 ± 0.05. Cultures growing on dung agar transferred by sporangia had a mean length to width ratio of 1.58 ± 0.12, while those growing on dung agar from hyphal tip transfers had a mean length to width ratio of 1.54 ± 0.19. Length to width ratios of sporangiospores produced during the first four days after the initiation of sporulation and those produced after different numbers of transfers are given in Tables 1 and 2.

DISCUSSION

Taxonomic descriptions of all species of *Pilobolus* contain observations about sporangiospore size and shape. Van Tieghem (1876) observed the spores of *P. longipes* to be 12-14 by 10-12 μm; these measurements were repeated by Fischer (1892). Grove (1934) followed the original description closely, stating that the spores were globose or ovoid, 12-15 by 10-12 μm. Zycha *et al.* (1969) expanded these measurements, stating that the spores were oval to oblong, 7.4-16.8 by 7.2-14.9 μm. Spores from the authors; experiments fall within these ranges with a mean length of 11.0 (range 9.1 to 13.6) μm and a mean width of 10.2 (range 8.7 to 12.0) μm.

Spores of *P. crystallinus* were observed by van Tieghem (1876) to be 8-10 by 5-6 μm; Fischer (1892) found the spores to be 5-10 by 3-6 μm. Grove (1934) stated that they were 5-10 by 4-6 μm. Zycha *et al.* (1969) observed that the spores were ellipsoidal, 5-12 by 3-7 μm. Spores from the authors; experiments fall within these ranges with a mean length of 9.3 (range 8.4 to 10.9) μm and a mean width of 5.9 (range 5.2 to 7.8) μm.

For both species, the ranges of spore sizes from the original descriptions and more recent observations give wide variations in sporangiospore sizes within species. Spores produced under all test conditions were within published taxonomic limits.

Sporangiospore sizes were remarkably consistent within a single sporangium. However, sporangiospores produced in different sporangia varied significantly in size from one sporangium to another, even when these sporangia developed from a single mycelium. This made it very difficult to compare sporangiospore sizes from sporangia produced on different days or after different numbers of transfers. The differences in sporangiospore sizes from different sporangia produced on a given day from a single mycelium were as great as those produced in different sporangia from subsequent transfers. Thus, it appears that there is no significant difference in sporangiospore sizes from cultures caused by time or number of transfers. In every case, the mean sporangiospore size from any sporangium was similar to that of all other mean sporangiospore sizes from that isolate. There was no pattern of sporangiospore size change over time or from subsequent transfers.

Describing the shape of sporangiospores by using the length to width ratio indicates overall sporangiospore shape without regard to the size of the spore. *Pilobolus longipes*, described as having globose, ovoid, or oblong spores had a length to width ratio of 1.08 ± 0.04 (range 1.01 to 1.19). No pattern of different ratios was seen on different days or after different numbers of transfers. *Pilobolus crystallinus*, described as having ellipsoid spores, had a length to width ratio of

1.57 ± 0.12 (range 1.38 to 1.81). Again, no pattern of different ratios was seen on different days or after different numbers of transfers.

No pattern of sporangiospore size or shape variation was seen in either *P. longipes* or *P. crystallinus* when transferred over a relatively long period of time. Individual sporangiospore size and shape fluctuations appeared between mean measurements of spores from different sporangia from different mycelia, but these were no greater than those from sporangia produced on the same mycelia. Mean sizes and shapes of sporangiospores from all sporangia were very similar and well within the ranges published in species descriptions. Variations in sporangiospore sizes and shapes from different sporangia were so small that these sizes and shapes may be used confidently in taxonomic descriptions.

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THIN LAYER CHROMATOGRAPHIC IDENTIFICATION OF PHENOL IN THE GLANDULAR SECRETORY SYSTEM OF *CANNABIS SATIVA* L. (CANNABACEAE)

Charles T. Hammond
Department of Biology
St. Meinrad College
St. Meinrad, Indiana 47577
and
Paul G. Mahlberg
Department of Biology
Indiana University
Bloomington, Indiana 47405

ABSTRACT: A phenolic glycoside was isolated from vegetative stem exudates from a Mexican strain of *Cannabis* and tentatively identified by thin layer chromatography (TLC) as phloroglucinol-glucoside. Incubation at 100°C for 30 min in 2N HCl liberated a free phenol which was identified by mass spectroscopy and ^{1}H-nuclear magnetic resonance as phloroglucinol. Glandular heads were isolated in large numbers with high purity from floral regions by blending, microfiltration and centrigugation in cold. Gland samples extracted for phenols as above revealed by TLC the presence of phloroglucinol. Phloroglucinol may play an important role in the *in vivo* biosynthesis of cannabinoids.

INTRODUCTION

Although there are over 300 cannabinoid or cannabinoid-related compounds reported as natural constituents of *Cannabis* (Turner, *et al.*, 1980) most strains of marihuana are characterized by the production of a biogenetically related series of compounds (Figure 1). Cannabinoids are terpenophenolic compounds believed to originate in the plant from condensation of a terpene derivative (such as geranyl pyrophosphate) with the phenol olivetol (as olivetolic acid) to form the cannabinoid series which includes cannabigerolic acid (CBGA), cannabichromenic acid (CBCA), cannabidiolic acid (CBDA), and $\triangle^9$-tetrahydrocannabinolic acid ($\triangle^9$-THCA) (Mechoulam, 1970; Shoyama, *et al.*, 1975). These cannabinoids occur naturally predominantly in their water-soluble acid forms but are readily decarboxylated to their water-insoluble neutral forms by mild heating or drying of plant tissues or extracts.

Glandular hairs, which are most abundant on the surface of pistillate floral bracts and bracteoles (Figure 2), have been studied developmentally (Hammond and Mahlberg, 1977) and ultrastructurally (Hammond and Mahlberg, 1978) and are considered to be a major site of synthesis and localization of these cannabinoids (Lanyon, *et al.*, 1971; Malingré *et al.*, 1975; Turner, *et al.*, 1977, 1978). In an effort to further characterize the glandular site and mechanism of cannabinoid biogenesis, thin layer chromatography (TLC) was used to screen, isolate, and identify

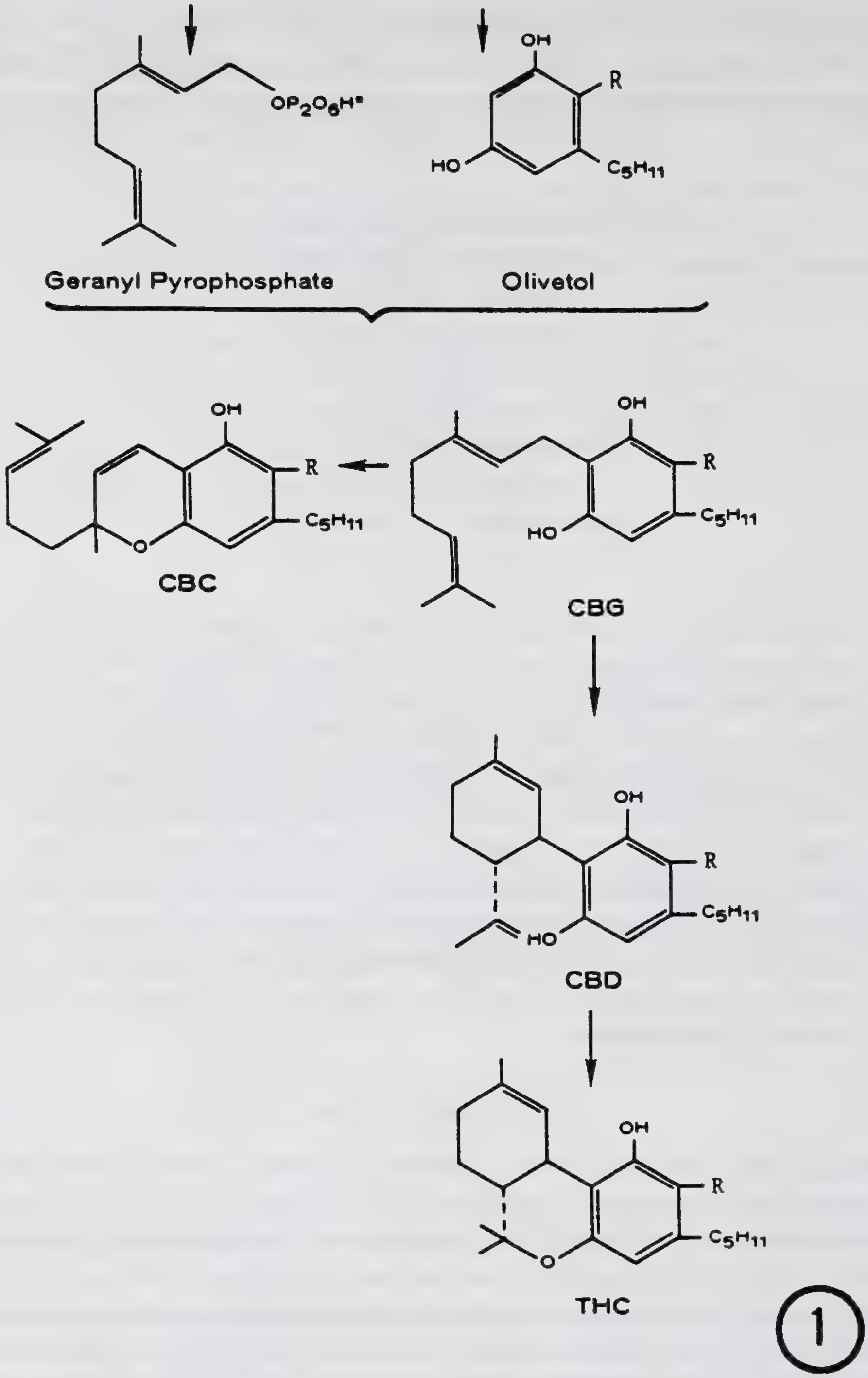
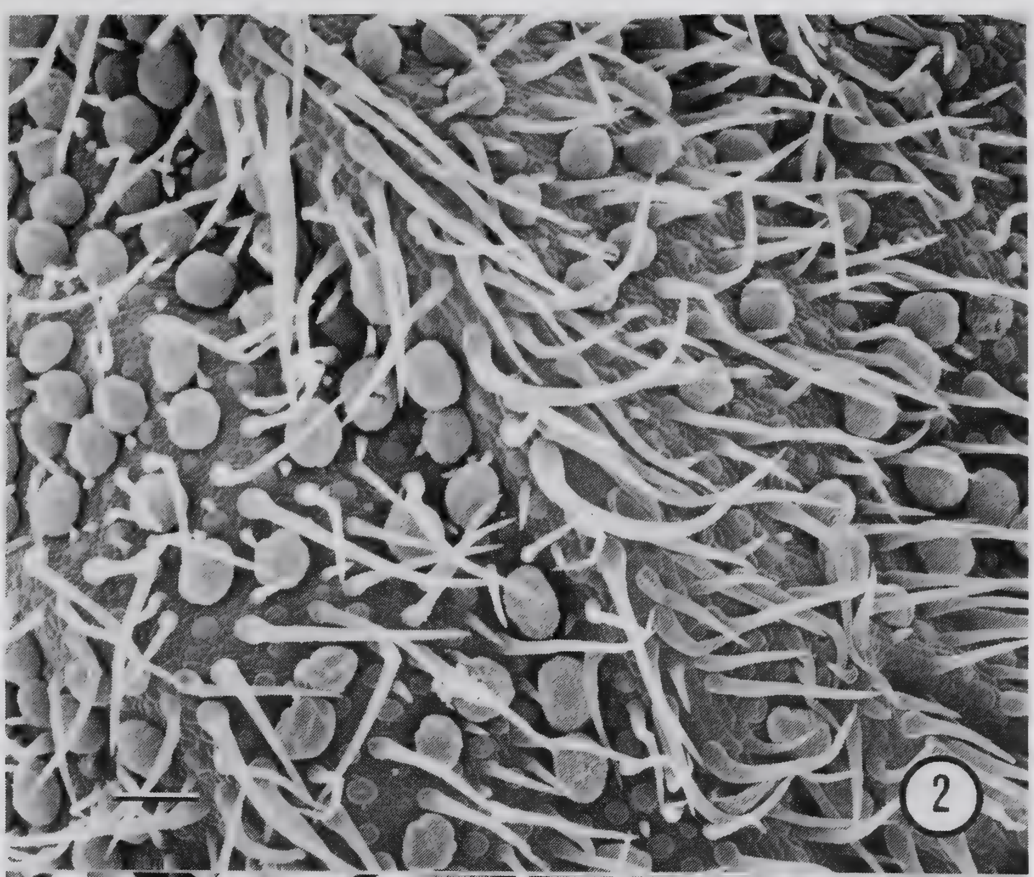


FIGURE 1. Biogenetic pathway for cannabinoid biosynthesis. Cannabinoids shown as neutral forms. Acid forms possess carboxyl group at R position.

major phenolics characteristic to *Cannabis* tissues and also common to glandular sites of synthesis.

MATERIALS AND METHODS

Roots, stems, leaves, petioles, bracts, and stem exudates of a Mexican strain of *Cannabis* were screened for phenolic profiles using a phenolic extraction and TLC separation procedure modified from Harborne (Harborne and Williams, 1969). Fresh tissues were typically blended in water in cold, filtered, adjusted to 2N with HCl, heated for 30-60 min at 105°C, extracted in peroxide-free ethyl



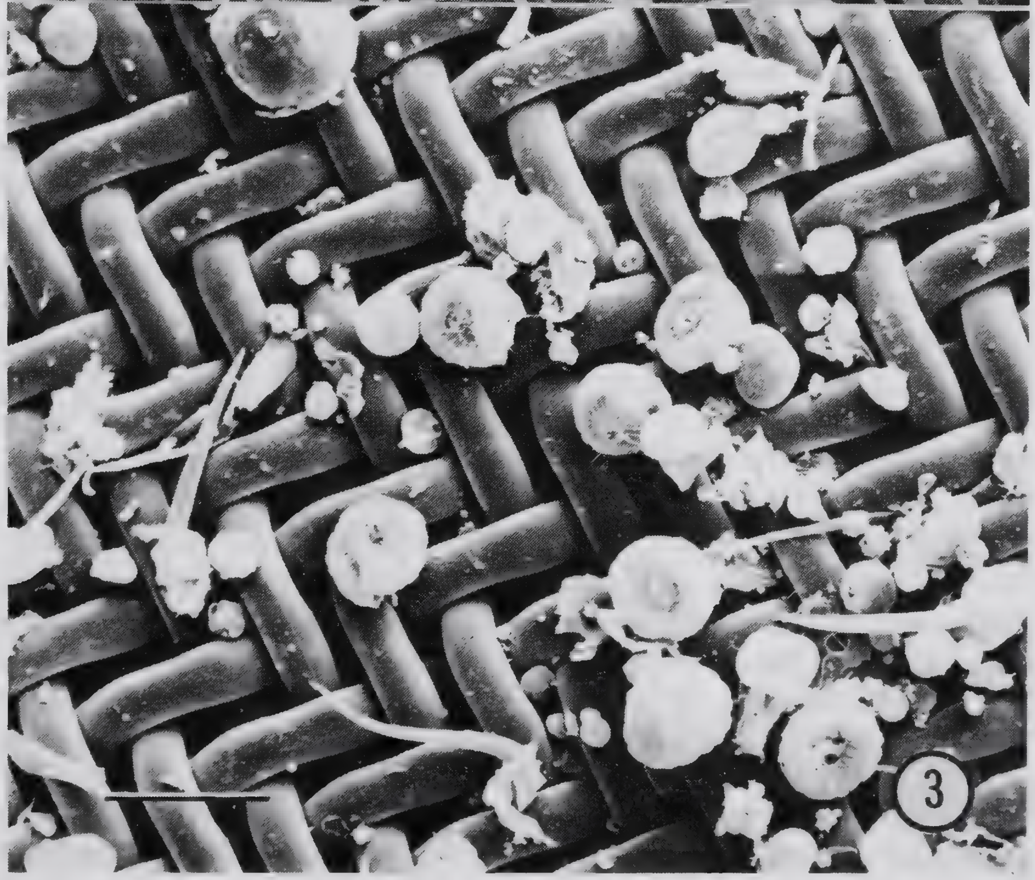


FIGURE 2. Glandular hairs on floral bract of *Cannabis*.

FIGURE 3. Purified glandular hairs isolated on Nitex by filtration. Bar = 100 μm.

ether, and concentrated to near dryness under nitrogen gas. Extracts were spottted at 1 to 3 μl on 5x10 cm strips of Eastman Kodak Chromogram Sheet 13179 Silica Gel and developed in a non-equilibrated capped jar using either a polar (ethyl acetate-methanol-aqueous 2% acetic acid; 67:7:1) or more non-polar (toluene-ethyl acetate-formic acid; 17:10:1) solvent. Visualization of phenolics was by long and short wave UV and spraying with a freshly prepared 0.1% aqueous-methanol (1:3) solution of fast blue salt B (FBSB).

Glandular heads were isolated in large numbers with high purity from floral regions by blending in cold sodium acetate buffer (pH 5.0) and filtration through cheese cloth followed by filtration through 20 mesh Nitex in a Buchner funnel (Figure 3). Glands were rinsed off the Nitex with cold buffer and concentrated by low speed centrifugation. Glands were then disrupted with an amalgamator, using 0.5 mm zirconium beads, and the supernatant was subjected to phenol extraction using the acid-heat treatment described above.

RESULTS

The most promising results from the initial screening were afforded by stem exudates which produced abundant phenol in simple profiles. Young stem regions of large vegetative shoots, when cut, produce abundant exudate presumably from phloem and associated laticifer elements. Thin layer separation of extracts of stem exudates are shown in Figure 4. These chromatograms are reconstructions for illustrative purposes of several chromatograms run at different times. The two chromatograms in Figure 4 are identical in setup except that "A" is run in the polar system and "B" in the more non-polar system. Reading from left to right on each chromatogram, Sample 1 is a mixture of cannabinoid standards (0.5 μl of 1 mg/ml) which run together near the solvent front at the top of the chromatogram and which stains red with FBSB. Sample 2 is an olivetol standard (0.5 μl of 10 mg/ml) which stains purple with FBSB. In the polar system, it runs close to the cannabinoid standards, but in the non-polar system, it is clearly separated from the cannabinoid standards running in the middle of the chromatogram. Our olivetol standard produced a faint second spot in the non-polar system at a slightly higher Rf position which was an artifact of undetermined origin. Sample 6 is the acid-heat treated extract of stem exudate. In the more polar system "A", three phenolic sports are resolved along with streaks of unresolved phenolics. In the non-polar system "B", nine phenolic spots are resolved. In both solvent systems, one purple staining spot appeared in greatest abundance and was targeted for further study.

Stem exudate (1.28 ml) from 64 large vegetative plants was collected, acid-heat treated, and extracted in ethyl ether as before, but separated by preparative thin layer chromatography in the non-polar solvent system. The abundant, purple staining phenolic of interest from the initial study was then isolated from the preparative chromatogram and taken to dryness. The extract yielded 1.4 mg of phenol per ml of stem exudate. This purified phenol sample was identified by proton nuclear magnetic resonance and mass spectroscopy as trihydroxybenzene, or, more commonly, phloroglucinol. These spectroscopy data will be published separately (Hammond and Mahlberg, in press).

When a phloroglucinol standard (Figure 4, Sample 3; upper Rf spot) was run against stem exudate extract (Figure 4, Sample 6), it had a similar purple color reaction with FBSB and ran at an identical Rf position as the abundant unknown

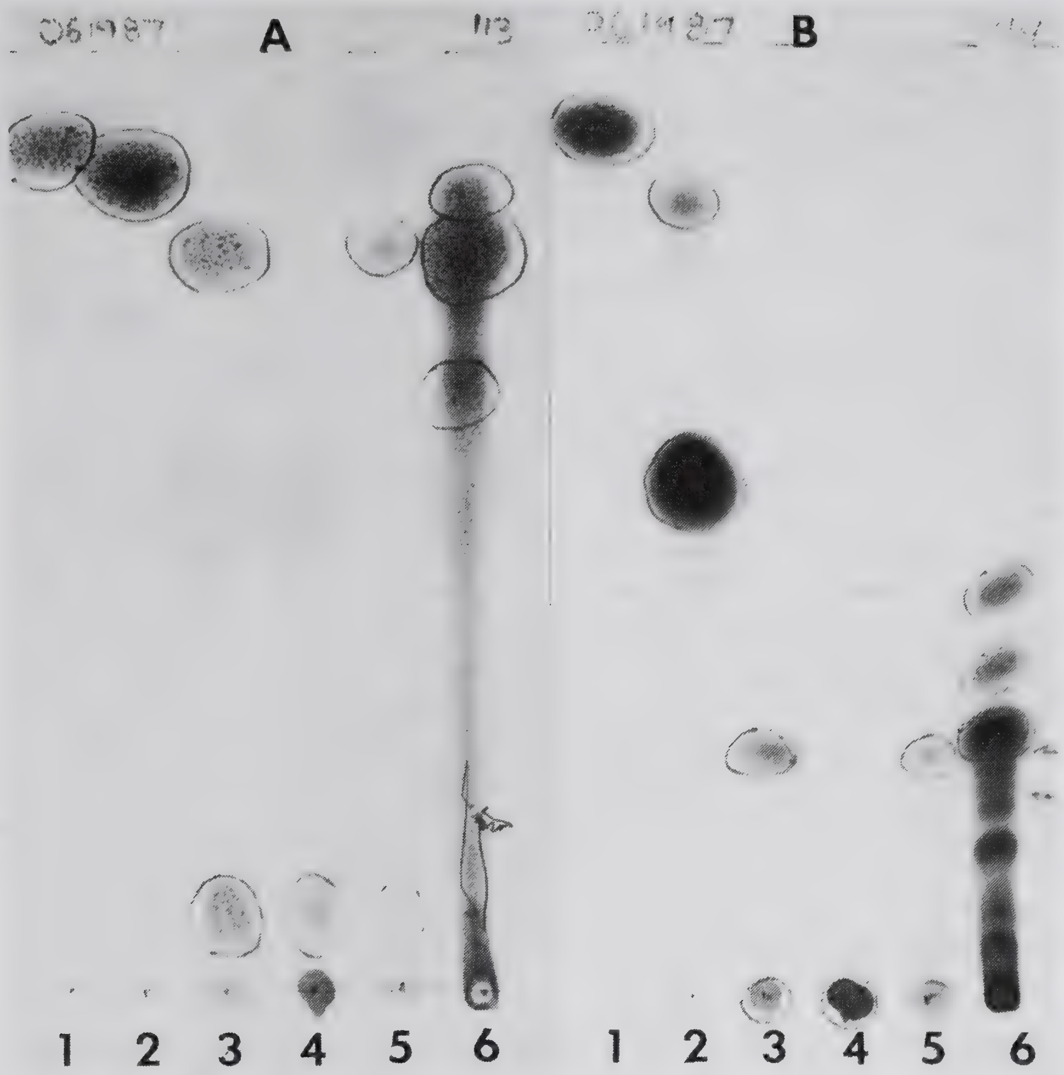


FIGURE 4. Demonstration of phloroglucinol glucoside in stem exudate of *Cannabis*. Chromatogram A developed in Ethyl acetate:methanol: 2% aqueous acetic acid. Chromatogram B developed in Toluene: Ethyl acetate: formic acid. See text for sample discussion.

phenol in both polar and non-polar solvent systems. This provided TLC confirmation that the unknown phenol was phloroglucinol.

Fresh stem exudate collected in 80% ethanol but not acid-heat treated produced a phenolic profile shown in Figure 4, Sample 4. In the polar system "A", a single, pink staining, low Rf spot was formed. Considering the polar nature of this spot, its association with phloroglucinol, its location in the phloem, the hydrolytic function of acid-heat treatment in phenol extraction, and the common existence of phenolics as glycosides, we postulated that the phloroglucinol in stem exudates may occur as a phloroglucinol glycoside. This was confirmed by preparation of a phloroglucinol β-d glucoside standard using a *Vicia* seed synthesizing system after Pridham (Pridham and Saltmarsh, 1963). This is shown in Figure 4, Sample 3, where the phloroglucinol glucoside standard (lower Rf spot) has a similar pink staining reaction with FBSB and an identical Rf position as the fresh stem exudate extract in chromatogram "A". Further confirmation was provided by incubation of the fresh stem exudate extract with β-d glucosidase (Sigma G-8625) as shown in Figure 4, Sample 5. In both chromatograms "A" and "B", phloroglucinol is liberated after enzyme hydrolysis.

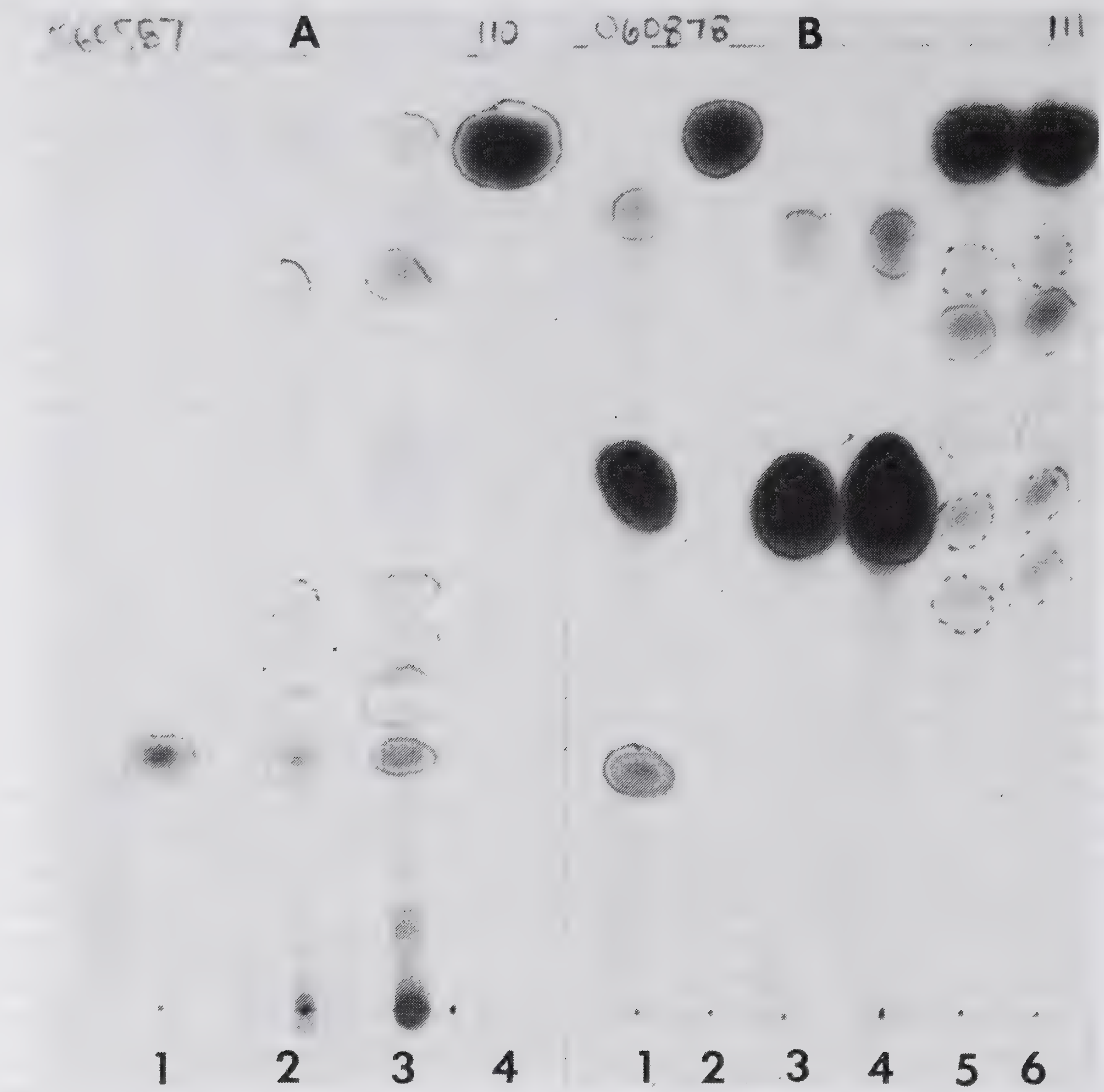


FIGURE 5. Demonstration of phloroglucinol in glandular hairs of *Cannabis*. Chromatograms A and B developed in Toluene: Ethyl acetate: formic acid. See text for sample discussion.

With the identification of phloroglucinol as a characteristic and abundant phenolic of stem exudate, it was important to ascertain if phloroglucinol was a characteristic phenolic of the glandular secretory system. Glandular heads were isolated in large numbers with high purity and subjected to phenol extraction using the acid-heat treatment as described previously. TLC of the glandular phenolic extract using the non-polar toluene-ethyl acetate-formic acid solvent system is shown in Figure 5, chromatogram "A". In Figure 5, reading from left to right, Sample 1 is a phloroglucinol standard (0.5 μl of 1 mg/ml), and Sample 4 is a mixture of cannabinoid standards (2 μl of 1 mg/ml). Figure 5, Samples 2 and 3 are 1 and 3 μl respectively of the gland phenolic extract. Note the presence of phloroglucinol as well as cannabinoids in gland heads.

Figure 5, chromatogram "B" demonstrates that phloroglucinol is a natural constituent of gland heads and not an artifact of acid-heat treatment breakdown of cannabinoids or even olivetol. In Figure 5, reading again from left to right, Sample 1 is a mixture of phloroglucinol (0.5 μl of 1 mg/ml) and olivetol standards (0.25 ml of 10 mg/ml). Figure 5, Samples 3 and 4 and 1 are 2 μl respectively of acid-heat treated olivetol standard. Figure 5, Samples 5 and 6 are 1 and 2 μl respectively of acid-heat treated cannabinoid standard mixture. Note that in neither the treated olivetol nor the treated cannabinoid mixture is phloroglucinol generated by the phenol extraction procedure. Acid-heat treatment of the cannabinoid mixture did generate "new" phenolic spots, which are clearly artifacts of the procedure.

DISCUSSION

The chemical composition of marihuana is characterized by the production of a series of terpenophenolic cannabinoids (Mechoulam, 1970). The presence of cannabinoids and their interactions with man, while generally known for millenia, have only recently received serious study. While man has either wanted to enhance or inhibit cannabinoid production in the plant, little has become known about natural cannabinoid biogenesis. The currently accepted biosynthetic pathway (Figure 1) deduced from structural and synthetic studies postulates that CBGA is the first cannabinoid to be formed in the plant by a condensation of an activated monoterpene such as neryl or geranyl pyrophosphate with the phenolic olivetol. CBGA is then a precursor to CBCA as well as separately to $\triangle^9$-THCA through CBDA (Mechoulam, 1970; Mechoulam and Gaoni, 1967; Shoyama, *et al.*, 1975). Recent work with an *in vitro* system using labeled isotope incorporation with developing seedlings found the first cannabinoid to appear to be CBCA not CBGA (Turner and Mahlberg, 1988). Similarly, Mexican strains of *Cannabis* produce abundant THCA but lack CBDA. Clearly, either the postulated pathway is in error, pathways undergo change during ontogeny, or more than one pathway is involved in cannabinoid biosynthesis.

The biogenetic scheme reported above is largely the result of a chemical systhetic approach rather than a botanical plant-related approach. Although THCA and other cannabinoids can now be readily synthesized from condensation of a variety of terpenes with olivetol (Churchill, 1983; Mechoulam and Gaoni, 1967), it is not clear that this is the mechanism of synthesis in an enzyme-mediated plant system. With this problem in mind, we thought it would be useful to intially approach the biosynthetic pathway by looking at phenolics in *Cannabis*.

It was clear from our initial results that olivetol was not present in stem exudates, nor could it be identified in our screening of all major organs of *Cannabis*. Instead, the major phenolic of stem exudates and glandular heads was phloroglucinol. Olivetol was tentatively identified, by TLC alone, as a decomposition product of acid-heat treatment of cannabinoids. There are reports of olivetol artifacts generated in marihuana smoke (Novotny, *et al.*, 1982) or in the high temperature injection port of the gas-liquid chromatograph (Bailey, 1978).

The presence of phloroglucinol, as a glucoside or glucoside derivative, as an abundant and characteristic phenolic of *Cannabis* glands and the absence of olivetol raises important questions about the *in vivo* mechanism of biogenesis of the marihuana cannabinoids. This study suggests that phloroglucinol may play an important role in the natural biogenesis of cannabinoids. It is of biological interest to note that *Humulus*, the only other genus in the family Cannabaceae, is widely reported to utilize phloroglucinol derivatives in the synthesis of its specialized terpenophenolic compounds, humulone and lupulone (Reidl, 1962).

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FIRST REPORT OF TOMATO SPOTTED WILT VIRUS (TSWV) ON FIELD-GROWN PEPPERS IN THE MIDWEST

R. X. Latin and G. E. Ruhl
Department of Botany and Plant Pathology
Purdue University
West Lafayette, Indiana 47907
and
S. T. Nameth
Department of Plant Pathology
Ohio State University
Columbus, Ohio 43210

Tomato spotted wilt was first observed in Australia in 1915 on tomatoes and was shown to be caused by a virus, TSWV, in 1930 (Francki and Hatta, 1981). TSWV particles are roughly spherical in shape approximately 85 nm in diameter with a lipoprotein envelope and may contain 4 major structural polypeptides. The nucleic acid of TSWV is a single-stranded RNA. The TSWV is now considered to have a world-wide distribution. It has been of great interest to plant pathologists, because of the serious diseases it can cause in a number of important crops, its extremely wide host range, and its transmission by thrips. TSWV appears to be the only virus transmitted by thrips.

In both greenhouse and field crops, over 170 species of plants in 35 different families are susceptible to TSWV. TSWV is seed transmitted in only one floral plant, *Cineraria* (R. K. Jones, NCSU, personal communication). The host range of ornamental plants includes cut flowers, pot plants, bedding plants, and some houseplants (Table 1). Tomato spotted wilt virus also affects non-ornamental field crops (Table 2), and numerous weed hosts (Table 3), which may serve as reservoirs for the virus.

Greenhouse epidemics of this virus disease had not been noted prior to the introduction of *Frankliniella occidentalis*, the western flower thrips (WFT), as the dominant species in the 1950's (Robb, *et al.*, 1988). The genetic potential of the virus for a significant rate of mutation along with the ability of WFT to develop insecticide resistance may have contributed to the rapid establishment of TSWV in greenhouse crops. Only thrips which acquire TSWV while they are in the larval stage can successfully transmit the virus to other plants as adults (R. Mau, U. HI, personal communication). Thus, the virus only survives for one thrips generation.

General symptoms of TSWV infection include ringspots and line patterns on leaves, stem necrosis, and a general ragged appearance due to developing necrotic areas on leaves. Symptom development may be slow on some plants and appears to be affected by the age of the plant and the stage of growth when infection occurs. Symptoms may also mimic those caused by *Phytophthora* root rot or other fungal wilts. Flowers may also become spotted or distorted (Nameth, *et al.*, 1988).

During the summer of 1988, samples of pepper plants showing symptoms typical of a virus disease were submitted to the diagnostic clinic for disease iden-

TABLE 1. Ornamental hosts of tomato spotted wilt virus (Best, 1968; Matteoni, *et al.*, 1988).

African Violet
Ageratum
Amaranthus
Amaryllis
Anemone
Aster
Begonia
Calceolaria
Calendula
Calla Lilly
China Aster
Christmas Pepper
Chrysanthemum
Cineraria
Coleus
Columbine
Cosmos
Cyclamen
Dahlia
Delphinium
Dusty Miller
Evening Primrose
Exacum
Forget-Me-Not
Fuschia
Geranium
Gerbera
Gladiolus
Gloxinia
Gypsophila
Impatiens
Lobelia
Lupin
Marigold
Morning Glory
Nasturtium
Poeny
Petunia
Phlox
Poppy
Primrose
Ranunculus
Salvia
Schefflera
Snapdragon
Stock
Tiger Lilly
Verbena
Zebra Plant
Zinnia

TABLE 2. Non-ornamental crop hosts of tomato spotted wilt virus (Best, 1968; Francki and Hatta, 1981).

Artichoke
Broad Bean
Cauliflower
Celery
Chicory
Coriander
Cos Lettuce
Cowpea
Eggplant
Endive
French Bean
Garden Pea
Papaya
Peanut
Peppers
Pineapple
Potato
Romaine
Snap Bean
Spinach
Sweet Pea
Tobacco
Tomato

TABLE 3. Weed hosts of tomato spotted wilt virus (Best, 1968; Cho, 1987).

Amaranthus spp.
Beggarticks (*Bidens* sp.)
Bindweed (*Polygonum* sp.)
Bull Thistle (*Cirsium* sp.)
Capsella sp.
Chickweed (*Stellaria* sp.)
Conyza bonariensis
Coreopsis
Crepis spp.
Emilia sp.
Gaillardia sp.
Godetia
Jimson Weed (*Datura* sp.)
Lambsquarter (*Chenopodium* sp.)
Malva sp.
Mesembryanthemum
Montia sp.
Nightshades (*Solanum* sp.)
Poppy
Saxifrage
Sow Thistle (*Sonchus* sp.)
Wild Tobacco
Yellow Sweet Clover (*Meliotus* sp.)

tification. The samples were from three separate commercial pepper fields in northern Indiana. Two of the fields near Plymouth were planted to sweet banana and sweet cherry peppers; the third field, in Highland, was planted to bell peppers. The sweet banana and sweet cherry samples were transplants which had been direct seeded into fumigated beds in Georgia, pulled and packaged, shipped into Indiana, and planted in late May. The bell peppers were raised in a greenhouse in northern Indiana and then transplanted to the field.

Symptoms of stunted plants were first noted in early July. In all three fields, less than 5% of the plants showed symptoms. The symptoms on diseased plants included distorted foliage and the ring patterns characteristic with TSWV. Diagnosis by symptoms alone, however, was not sufficient, since tomato ringspot virus and several other viruses also cause similar symptoms on peppers. Thus, serological confirmation of the suspected virus via Enzyme Linked Immunosorbent Assay (ELISA) was necessary. Samples of leaf tissue were sent to Dr. C. Sutula at AGDIA, a privately owned company in Mishawaka, Indiana, which performs serological testing for numerous virus diseases on a number of different hosts. Samples were also sent to Dr. S. T. Nameth at Ohio State University in Columbus, Ohio. Both labs confirmed the presence of TSWV in the leaf tissue via the ELISA technique. In addition, Dr. Nameth used double-stranded RNA (dsRNA) analysis to confirm the TSWV diagnosis. No dsRNA was present in the pepper tissue, thus ruling out tomato ringspot virus and other pepper virus diseases containing dsRNA. With two independent positive ELISA results and the negative dsRNA result, we felt confident of our diagnosis of TSWV as the causal agent. Future studies could include detection of inclusion bodies in infected tissue (Christie and Edwardson, 1986) and the use of bioindicator plants (Nameth, *et al.*, 1988).

As the summer progressed, the disease incidence remained less than 5%. However, the severity of the symptoms increased. The lack of disease spread in the field was attributed to the absence of the WFT vectors. The pepper plants were apparently infected as young seedlings (both in Georgia and in the greenhouse situation). Perhaps, the symptoms were not visible until a later date due to a long incubation associated with TSWV infection. Notably, the Indiana greenhouse which housed the pepper seedlings also housed the floriculture seedlings, thus increasing the chance of the presence of the WFT.

In conclusion, the occurrence of TSWV in the field has raised several questions concerning:

1. Commercial growing practices such as those of mixing floricultural and vegetable crops in the same greenhouse;
2. Proper control strategies for the disease;
3. The possibility of new strains of TSWV; and
4. The necessity of disease-free transplants.

The first step in control is to get rid of infected plants. This is easier said than done, especially since plants may harbor the virus but show no symptoms. In addition, weeds must be eliminated in and around greenhouses and fields. Before killing weeds or discarding infected plants, they should be sprayed with an insecticide effective against thrips to lessen the chance that the insects will disperse as plants are moved or as weeds begin to die. The second major way in which TSWV can be managed is to control thrips. Management of WFT on greenhouse ornamentals and vegetables is extremely difficult. A combination of physical exclusion as well as cultural and chemical methods must be used to keep populations low enough to prevent visible plant damage and/or slow the spread of the TSWV. The use of yellow sticky traps to monitor thrips population trends is also extremely important.

The importance of healthy transplants for the commercial vegetable industry as well as the ornamental industry is a point which is often overlooked. Growers must be aware of potential problems and strive to produce disease-free transplants.

Recipients of transplants should take precautions to stave off the spread of potential problems by:

1. Refusing infected plants;
2. Monitoring fields and greenhouses for the Western Flower Thrips and other thrips;
3. Observing plants in the greenhouse and field for symptom expression; and
4. Being ready to initiate control procedures.

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A COMPILATION OF PLANT DISEASES AND DISORDERS IN INDIANA - 1988

Gail E. Ruhl, Richard X. Latin, Donald H. Scott, and Paul C. Pecknold
Department of Botany and Plant Pathology
Purdue University
West Lafayette, Indiana 47907

INTRODUCTION

The Plant Diagnostic Clinic in the Department of Botany and Plant Pathology at Purdue University is a service of the Cooperative Extension Service, Purdue Agricultural Experiment Station. Plant disease diagnosis and weed identification are gratuitous services offered by the clinic. Of the 1176 specimens received, approximately 85% were submitted by county extension agents. The remainder of samples came directly from commercial growers, homeowners, private consultants, and other interested persons. This paper is a summary of the major plant diseases and disorders which were diagnosed in the clinic and observed throughout the State in 1988. A number of reports exist which will allow this data to be compared with what has been encountered in the past (Evans, *et al.*, 1980; Evans-Ruhl, *et al.*, 1986, Pecknold, *et al.*, 1974; Ruhl, *et al.*, 1982-1986).

METHODS

Specimens are diagnosed visually or by culturing the pathogen on selected media. Some virus diseases are diagnosed by the leaf dip (negative stain) technique, utilizing the electron microscope. Serological rapid assay detection is also utilized. Once a disease or disorder is diagnosed, appropriate control measures are suggested. A summary of the samples diagnosed from January 1 through October 31, 1988 is given in Table 1.

RESULTS

As of October 31, 1988, the clinic had received 1176 samples, including agronomic, ornamental, fruit, turf, and vegetable crops (Table 1). Of these samples, approximately 37% were diagnosed as infectious disease problems, 27% were diagnosed as environmental/site disorders, 8% were diagnosed as chemical injury, and 4% exhibited a nutritional problem. The remaining samples were either damaged by insects, were poor samples, or lacked adequate information for a proper diagnosis. Drought and heat stress were diagnosed as the most common causes of poor growth and reduced yields in 1988.

SHADE AND ORNAMENTAL TREES

Diseases. The drought of 1988 resulted in fewer leaf diseases than in previous years. Apple scab of crabapples, anthracnose of sycamore and ash, rust on hawthorn and crabapples, and *Diplodia* tip blight of pine were almost nonexistent due to the extreme dry conditions. Ash trees infected with ash yellows showed no immediate effects from the drought. However, it is suspected that ash decline will intensify in 1989 due to the drought conditions. Bacterial leaf scorch of northern red oak, caused by a xylem-inhabiting bacteria (XIB), was confirmed from a 20

TABLE 1. Plant samples received in the Purdue Plant Diagnostic Clinic January 1 through October 31, 1988.

Number of Plant Specimen[1]	Samples	Diseases[2]	Disorders[3]	Chem.[4]	Nutr.[5]	Insect[6]	Other[7]
Agronomic							
Corn	99	16	47	32	17	10	11
Soybeans	164	103	15	42	9	30	21
Small Grain	64	53	11	2	2	0	10
Forage Grasses and Legumes	21	12	5	0	1	3	2
Ornamental							
Trees-Shade and Ornamental	264	40	127	5	5	57	63
Shrubs and Groundcover	98	38	43	4	2	11	20
Flowers	54	27	7	4	4	8	12
House Plants	15	6	5	0	1	3	2
Fruit							
Tree Fruit	47	22	15	0	0	8	3
Small Fruit	37	11	10	3	0	5	9
Vegetable	99	41	19	5	5	16	22
Turfgrass	55	61	13	0	0	3	5
Plant I.D.	159	-	-	-	-		
Total	1176	430	317	97	46	154	180

[1] The number of diagnosed problems add up to more than the number of samples received, since many samples may have more than one problem.

[2] Problems caused by an infectious disease causing agent; e.g., fungus, bacterium, virus, mycoplasma, or nematode.

[3] Problem caused by noninfectious environmental stress; e.g., wind, drought, heat, or soil compaction.

[4] Problem caused by herbicide/pesticide misuse.

[5] Problem caused by a nutrient imbalance.

[6] Problem caused by an insect. Does not include samples submitted to the Entomology Diagnostic Clinic.

[7] "Other" includes the causal agent categories no disease and inadequate sample for diagnosis (4 parasitic seed plants (dodder)).

year-old street tree in West Lafayette. Reports of XIB also causing leaf scorch of sycamore and elm in eastern and southern States suggests the same association may be present in Indiana.

Disorders. The drought of 1988 was the predominant disorder. The degree of drought stress to forest and landscape trees varied across the State. Generally, trees in the southern part of the State were in better condition than in the northern part of the State. Site location, tree vigor, and tree age were major factors in determining the degree of drought injury. Street trees in restricted growing sites were especially vulnerable to the drought and showed extensive dieback and leaf scorch. Drought caused 80% mortality to scotch pine seedlings in a number of Christmas tree plantings and slowed the growth of young pine plantings and deciduous nursery plantings. During late summer, there were numerous reports from throughout the State of premature leaf yellowing and drop on tulip tree, maple, sycamore, and walnut. The full effects of drought damage will probably not be seen until the 1989 growing season. Further tree mortality and decline will occur through 1989 and beyond, as a result of the 1988 drought.

ORNAMENTALS

Diseases. There were no widespread diseases of major occurrence on ornamentals, in large part due to the extreme dry conditions. As in previous years, powdery mildew was prevalent during late summer on lilac, zinnia, dahlia, and numerous other susceptible hosts. A case of downy mildew on greenhouse-grown roses was also diagnosed.

Disorders. Drought injury was most common on shrubs in an already weakened condition and on newly planted ornamentals. Winter desiccation (browning) of junipers and other evergreens was common but not severe.

TREE FRUITS

Diseases. Apple scab, cedar apple rust, and other early season leaf and fruit diseases were of minor occurrence due to persistent dry weather throughout the growing season. Apple scab was the lightest its been in the last 15-20 years. Surprisingly, fire blight of pear and apple was reported from a number of orchards in southern and central Indiana. The majority of damage was due to blossom blight (especially common on late bloom) rather than the more common twig blight. Continued dry conditions through summer held most common summer diseases in check. However, rainfall in July and August resulted in moderate to light infection from sooty blotch and fly speck of apple fruit.

Disorders. The drought of 1988 resulted in smaller fruit size and further stress on already weakened trees. The full effects of drought damage will prpbably not be seen until after winter and into the 1989 growing season. The extent of damage was widely variable depending on orchard/tree location, the availability of irrigation, and the age of the trees.

SMALL FRUITS

Diseases. There were no outstanding infectious diseases reported on small fruit, no doubt in part due to the dry conditions. Typical fungal leaf spotting occurred on strawberries and brambles toward the end of the season.

Disorders. Where irrigation was lacking, the drought resulted in a high incidence of mortality to new plantings.

VEGETABLES

Diseases. Most of the diseases that normally plague commercial vegetable production in June and July caused little concern this year. There were isolated cases of bacterial speck on tomato (*Pseudomonas tomato*), black rot of cabbage (*Xanthomonas campestris*), *Alternaria* leaf blight of muskmelon (*Alternaria cucumerina*), and bean root rot (*Fusarium, Pythium, Rhizoctonia*). Non-irrigated growers did not have to try too hard to control those diseases this year, but it was business as usual for growers with irrigation! Late season diseases took their usual toll. Early blight (*Alternaria solani*) on potato was especially severe in some fields. Gummy stem blight of melons (*Didymella bryoniae*) and black rot of squash and pumpkins threatened all cucurbits from August through September. Tomato anthracnose (*Collectotrichum coccodes*) and white mold on green beans (*Scerotinia sclerotiorum*) were widespread.

Virus diseases caused as much concern as any other vegetable crop disorder (except drought) in 1988. Watermelon Mosaic Virus (WMV) was diagnosed in all parts of the State on muskmelons, cucumbers, squash, and pumpkins. Incidence of WMV may have been unusually high this year, because many growers delayed planting as long as they could due to the dry spring. That allowed plenty of time for the virus to multiply within weed hosts and to be transmitted to cucurbits by aphids. The earlier the virus infects, the greater the damage to the crop. Some late pumpkins and cucumbers that were infected with WMV produced only a fraction of what they would normally yield. The virus is reported to be mechanically transmitted but is not carried in the seed.

A new virus was diagnosed on peppers for the first time in Indiana. The virus, tomato spotted wilt virus (TSWV), was identified in two commercial pepper fields in northern Indiana. This was the first time that TSWV was found on crops outside of the greenhouse in the Midwest. TSWV is transmitted by the Western Flower Thrips. It is not known to be seedborne in pepper or transmitted mechanically. Therefore, unless fields are continuously inhabited by the thrips vectors, disease incidence (percentage of infected plants) should not change over the season, although disease severity (the extent to which an individual plant is affected) is expected to increase. Many plant pathologists across the country are conducting research on TSWV to learn more about the nature of the virus and how to control it in our commercial fields.

Disorders. Two noninfectious disorders on tomato, blossom end rot and physiological leaf roll, were commonplace nuisances for homeowners.

AGRONOMIC CROPS

Diseases of Corn. The hot, dry weather conditions that persisted throughout Indiana during much of the growing season led to unusually high occurrences of *Fusarium* seedling blight, *Fusarium* stalk rot, *Fusarium* ear rot (all caused by *Aspergillus flavus*) in the State. These disease problems were general throughout the State but were more damaging in those areas that were most drought stressed. *Fusarium* seedling blight reduced stands in some fields but was more prevalent as a cause of uneven corn development and as a stalk rot later in the season. Common smut was the most prevalent in recent memory with as much as 25% of the ears infected in some fields.

A harvest survey was conducted by the Indiana State Chemist's Office for the presence of aflatoxin in the State. As of October 27, 1988, a total of 295 samples were analyzed. Of this total, 22 samples (7.5%) contained over 20 parts per billion (ppb) and 29 samples (17.3%) contained under 20 ppb aflatoxin (primarily B*1*). Aflatoxin production was found in samples scattered over the State but was more prevalent in the western half and most prevalent in the northwestern and southwestern regions. Concentrations of aflatoxin appeared to be higher in the western half than the eastern half of the State. The highest concentration of aflatoxin in the harvest survey was 129 ppb. One sample submitted to the Plant Diagnostic

Clinic by a Morgan County grower with severely drought stressed corn was found to contain 505 ppb aflatoxin.

In addition to *Fusarium* stalk rot, anthracnose stalk rot (*Colletotrichum graminicola*) was a common occurrence. Diplodia stalk rot (*Stenocarpella maydis*) and charcoal stalk rot (*Macrophomina phaseolina*) occurred in portions of southern Indiana. As in 1987, Diplodia ear rot (*S. maydis*) caused significant losses in 1988 in some southern Indiana fields where corn followed corn with reduced tillage practices.

There were no known yield losses in 1988 due to foliar diseases of corn. However, late in the season, minor amounts of northern corn leaf blight (*Exserohilum turcicum*), southern corn leaf blight (*Bipolaris maydis*), northern corn leaf spot (*Cochliobolus carbonum*), grey leaf spot (*Cercospora zeae-maydis*), and common rust (*Puccinia sorghi*) were observed.

Disorders of Corn. Drought and heat stress related factors were the most common abiotic causes associated with poor growth, delayed tassel development, poor pollenation, and severely reduced yields.

Diseases of Soybeans. Charcoal root rot (*Macrophomina phaseolina*) was more widespread and damaging in Indiana in 1988 than in any previous recorded year. The disease was observed in most areas the State at all stages of plant growth from seedlings to maturity and caused significant yield losses in some fields.

The soybean cyst nematode (SCN; *Heterodera glycines*) continued to increase in prevalence and severity in the western half of the State. SCN is the most significant problem affecting soybean production in those areas of the State where the nematode populations are high enough to cause economic damage. Both SCN and charcoal root rot are exacerbated by drought conditions.

Rhizoctonia root rot (*Rhizoctonia solani*) was found in many areas of the State but was easily confused with charcoal root rot, especially early in the growing season. Sudden death syndrome (SDS; *Fusarium solani* race A suspected) was observed primarily in southwestern Indiana again in 1988, but disease severity was light except in a few isolated fields. SDS was also identified in a single field in White County, but damage was very light. The geographic range of SDS in Indiana in 1988 was similar to that in 1987.

Brown spot (*Septoria glycines*) developed at mid-season in a few east-central Indiana fields and in other areas of the State later in the season. Damage was minimal. Other foliar and stem diseases, such as bacterial blight, downy mildew, and stem canker, occurred infrequently and at very low levels.

Pod and stem blight (*Diaporthe/Phomopsis* spp.) and Purple seed stain (*Cercospora kikuchii*) seed infections were observed in scattered areas of the State. However, the most significant seed problem in the State was the shriveled, discolored seed which resulted from drought and temperature conditions.

Disorders of Soybeans. Hilum bleeding or splotching (a discoloration of the seed coat which emanates from the hilum, diffuses away from the hilum, and has the same color as the hilum) was observed in several scattered areas of the State. Hilum bleeding is often associated with soybean mosaic virus (SMV) infection; however, both ELISA and grow out tests with affected seed failed to indicate the presence of SMV. Observations indicated that affected seed came from plants with heavy bean leaf beetle feeding on the pods. The etilogy of this discoloration remains unknown at this time.

Splitting of green pods at the pod suture about the R_6 was observed primarily in the middle third of the State. First reports of this disorder were received from east-central Indiana. Within several days, the condition had been reported from several areas extending to the western portion of the State. Observations indicated that plants affected by drought and with heavy spider mite infestation were the most likely to exhibit pod splitting. We currently believe that the abnormal pod splitting was the result of a combination of environmental stresses and spider mite feeding, affecting the water relations of affected plants.

Leaf rugosity, similar to that produced by hormone type herbicides, was a common complaint in many areas of the State around mid-season. While some complaints were judged to be the result of herbicide drift or volatilization, several complaints were not diagnosed. ELISA tests for soybean mosaic virus were negative.

Drought and heat stress were the most common causes of abiotic factors associated with poor growth and reduced yields.

Diseases of Wheat. Wheat spindle streak mosaic virus (WSSMV) symptoms were evident in many wheat fields in the State in early spring; however, field losses were minimal. Barley yellow dwarf virus (BYDV) was probably the most widely distributed disease of wheat and other small grains in the State. Yield losses undoubtedly occurred, but field losses due to drought and high temperatures precluded any yield loss estimates due to BYDV. Wheat streak mosaic virus (WSMV) was identified by ELISA tests from southwestern Indiana. *Rhizoctonia* leafspot on winter wheat was prevalent on wheat which was planted too deeply.

Disorders of Wheat. While several common foliar disease pathogens were present in wheat fields throughout the State in early spring, the excessively dry weather during the growing season precluded any of these pathogens from developing to significant levels. In general, wheat was free from disease in 1988, except for the virus diseases discussed above.

Diseases of Alfalfa. Alfalfa was relatively free from significant infectious diseases in 1988. Crown root-rot complex (a complex of pathogens) was exacerbated by the hot, dry growing conditions prevalent in the State in 1988.

TURFGRASSES

Kentucky bluegrass (*Poa pratensis*). Helminthosporium leaf spot (*Drechslera poae*) was present throughout the State but was not damaging due to the hot, dry weather. Necrotic ring spot (*Leptosphaeria korrae*), summer patch (*Magnaporthe poae*), and brown patch (*Rhizoctonia solani*) were common and damaging diseases in many areas of the State. In many cases, it was impossible to separate the effects of these patch diseases and the effects of drought as the cause of plant death.

Bentgrasses (*Agrostis palustris*). Brown patch (*R. solani*) wasthe most prevalent disease in the State. Where left untreated (without a fungicide), this disease became severe. Dollar spot (*Lanzia* or *Moellerodiscus* spp.) occurred in late season. Most bentgrass problems in the State were the result of severe stresses due to low mowing height and drought. *Pythium* blight (*Pythium aphanidermatum*) was a minor problem on some golf course greens and tees.

Annual bluegrass (*Poa annua*). Anthracnose (*Colletotrichum graminicola*) was severe during the extremely hot conditions in August; however, it was impossible to separate the effects of this disease and the severe environmental stresses caused by the drought.

Ryegrass (*Lolium perenne*). *Pythium* blight (*P. aphanidermatum*) was damaging in a few home lawn and golf course fairways in August.

Fescue (*Festuca* spp.). Red thread (*Laetisaria fuciformis*) was observed causing problems in a few home lawns.

Numerous turf areas suffered extensively from the extreme temperatures and drought conditions prevalent throughout the State.

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CELL BIOLOGY

Chair: JOAN ESTERLINE LAFUZE
2325 Chester Blvd.
Richmond, IN 47374

Chair-Elect: MARGARET EGAR
Department of Anatomy
Indiana School of Medicine
635 Barnhill Road
Indianapolis, IN 46168

ABSTRACTS

Role of Lipids in Tumor Cell Sensitivity to Cell-mediated Lysis. MARINA ABRAHAM, LAURA JENSKI, and WILLIAM STILLWELL, Department of Biology, IUPUI, Indianapolis, IN 46223.—Lymphocyte-mediated cytolysis may be an important mechanism for immune defense against cancer. Because cytolysis begins at the surface membrane, changes in lipid content of the tumor cell membrane may affect cytolysis. We fed BALB/c mice basal diets supplemented with 20% menhaden oil (rich in omega-3 polyunsaturated fatty acids) or coconut oil (rich in saturated fatty acids). After 6 weeks, we inoculated the mice with a tumor cell line, T27A, and allowed the tumor cells to grow for one week. Subsequently, we tested the tumor cells' sensitivity to lymphocyte-mediated killing with a standard radiolabel release assay. In two of three experiments, tumor cells grown in mice fed menhaden oil were more sensitive to cytolysis than those grown in coconut oil-fed mice. We propose that increased levels of polyunsaturated fatty acids in the tumor cell membrane correlate with alterations in membrane fluidity and enhanced sensitivity to cytolysis. Currently, we are modifying tumor cells *in vitro* with purified polyunsaturated fatty acid (docasohexaenoic acid, C22:6) or saturated fatty acid (stearic acid, C18:0) to explore this relationship.

Effect of Betaine on the Fine Structure of Salt-treated *Escherichia Coli*. MOHINDER S. JARIAL and DUNCAN T. KENNEDY, Indiana University School of Medicine, Muncie Center for Medical Education, Ball State University, Muncie, IN 47306—*Escherichia coli* 1130B-2ATCC was grown on nutrient agar medium, ir medium + 0.8M NaCl, or medium + 0.8M NaCl + 0.001M betaine. Each dish was innoculated with 10^{-7} bacteria and allowed to grow 72 hours. Colonies were fixed in gluteraldehyde, osmic acid and phosphate buffer. Three times as many colonies grew in the presence of NaCl and betaine grown on normal medium and on NaCl-betaine medium appeared as single gram-negative rods. However, those grown on NaCl medium appeared as long strings. Under the EM, bacteria grown on normal medium exhibited mesosomes and trilaminar outer and inner membranes separated by a peptidoglycan containing periplasmic space. The electron dense cytoplasm contained various granules. Nuclear material appeared as fine filaments. Bacteria grown on NaCl medium displayed vesicles being pinched off from the outer membrane which at many sites was disrupted resulting in loss of cellular contents. Nuclear material appeared in dark clumps and the cytoplasm exhibited membranous whorls and an increase in dense particles. Aberrant mesosomes were observed and cell division seemed to be arrested. Bacteria grown on

NaCl betaine medium appeared as normal rods. Their outer and inner membranes were intact, cytoplasm was fairly condensed and nuclear material appeared as fine filaments. This study suggests that betaine acts as a strong osmoprotectant for *E. coli* against high NaCl concentrations by maintaining the integrity of its membranes and nuclear material.

Effect of Dietary Stearic and Linoleic Acids on Mammary Gland Development in Strain A/St Mice. M.I. Lee and A.S. Bennett. Joliet Junior College, Joliet, IL 60436 and Ball State University, Muncie, IN 47306.—Promotion of murine mammary preneoplastic lesions and tumors are related to dietary fat intake. The effect of dietary stearic (SA) and linoleic acid (LA) on mammary ductile and alveolar development in mice that produce a high level of spontaneous mammary tumors was compared. Dietary polyunsaturated fats, specifically LA, promote tumor formation whereas stearic acid decreases tumorigenesis. Mammary glands were excised from 6 and 10 month old mice fed high fat (15%) LA rich or SA rich diets and from those fed low fat (5%) LA rich or stock diets. Inguinal glands were weighed and whole mounts were prepared for microscopic examination. Mammary glands of mice fed either high or low fat LA rich diets exhibited earlier development than those from mice fed high fat SA rich or stock diets and had poorly organized mammary ductile trees. These observed differences in early development may account for the reported SA inhibition and LA enhancement of the neoplastic progression.

ESR Determination of Cell Volumes. Valerie J. Spitzer, F.W. Kleinhans, Patty Villines, K.E. Colvin, and J.K. Critser, Dept. of Medical Research (FWK & VJS) and Ctr for Reproduction and Trans-plantation Immunology (PV, KEC, & JKC), Methodist Hospital Inc, of Indiana, Indianapolis, IN 46202 and Dept of Physics (FWK), IUPUI, Indpls, IN 46223.—Electron spin resonance (ESR) was used to determine the volume and osmotic properties of human red blood cells (RBC), for calibration, and spermatozoa. Cells volumes are determined by labeling a cell suspension with the aqueous label, tempone @ 2mM, and eliminating the extracellular signal via magnetic broadening using 35 to 50mM of membrane impermeable CrOx leaving an intracellular aqueous signal proportional to the volume of the cells. We obtain an ESR human RBC total volume of $97 \pm -10\ \mu m^3$ which compares well with the accepted mean of $88\ um^3$. For human sperm we obtain a total volume of $49.6 \pm - 8.9\ \mu m^3$ which is significantly larger then the typically quoted volume of $17.4 \pm 1.46\ \mu m^3$ based on Coulter Counter measurements. We believe the Coulter measurements suffer from the use of dead sperm and errors associated with the unusual shape of the sperm and their large size relative to the Coulter orifice.

A Cytological and Behavioral Study of Cord-Lesioned Axolotls. Marcy Thomas, IAS Summer Fellow, Science Teacher at Trinity Luthern, 8540 East 16th Street, Indianapolis, IN 46220 and Margaret W. Egar, Anatomy Department, Indiana University School of Medicine, 635 Barnhill Drive, Indianapolis, IN 46223.—In a remarkably short time, axolotls *(Ambystoma mexicanum)* will recover normal swimming behavior following a complete transverse lesion of the spinal cord. The present series of experiments involved making cord cuts at thoracic level T4-5 in 25 juveniles from different spawnings, aged 5 to 11 months. The recovery period was studied and individual behavioral patterns were recorded and compared to the age and size of the axolotl. Periodic samples were made for light microscopic study of the cord, including areas cranial and caudal to the lesion site. Sections stained with H and E, Bodian's silver stain, and alcian blue were prepared and studied. Special attention was paid to the ependymal-like cells that infiltrate the lesion site as early as the beginning of the second post-operative week and to the marginal neurons that are situated in a column just deep to the pia at lateral edge of the cord. Behavioral observations were a good indication of regeneration of axons across the lesion.

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THE CONTROL OF CELL DIFFERENTIATION AND GROWTH BY RETINOIC ACID MAY BE RELATED TO ITS EFFECT ON TRANSPLASMA-MEMBRANE DIFERRIC TRANSFERRIN REDUCTASE

Edna E. Sun, Iris L. Sun, and Frederick L. Crane
Department of Biological Sciences
Purdue University
West Lafayette, IN 47907

INTRODUCTION

The induction of cell differentiation or maturation by retinoic acid is well documented (Amatruda and Koeffler, 1986; Chou, 1982; Chou and Ito, 1984; Lotan and Lotan, 1980; Sherman, 1986; Strickland and Mahadavi, 1978; Strickland, *et al.*, 1980; Yen, *et al.*, 1987). Retinoic acid also inhibits the growth of several types of cells (Lotan, 1980; Roberts and Sporn, 1984). Relatively little is known about the mechanism of retinoid-induced cell differentiation. It is generally believed that a cellular retinoid-binding protein mediates the control of cell differentiation (Chytil and Ong, 1984; Sherman, 1986). Additionally, a retinoic acid-binding protein (site of action) in plasma membrane has also been described (Cope and Boutwell, 1983; Sani, 1979).

Reduction of impermeable oxidants by a transplasma membrane electron transport system stimulates proliferation of HeLa (Sun, *et al.*, 1985) and melanoma cells (Ellen and Kay, 1983). This electron transport system acts as a diferric transferrin reductase (Navas, *et al.,* 1986), because the external diferric transferrin is reduced, while cytosolic NADH is oxidized (Löw, *et al.*, 1987). Transferrin is a component of serum, and it has been shown to replace serum in the growth of many types of cells (Hutchings and Soto, 1978). Furthermore, cell proliferation has been related to expression of transferrin receptor (Miskimins, *et al.*, 1986). Therefore, diferric transferrin (Fe_2Tf) can be the natural oxidant for growth stimulation by transplasma membrane electron transport (Sun, *et al.*, 1984). In this study, retinoic acid is shown to inhibit the transplasma membrane NADH diferric transferrin reductase acitity. The inhibition of this enzyme may explain the growth inhibition by retinoic acid. The study with BALB/3T3 and SV/T2 cells also indicates that a correlation exists between morphology, proliferation index, and this enzyme activity. Recently, an association with growth arrest has been observed during retinoic acid-induced differentiation of F9 cells (Dean, *et al.*, 1986). The inhibition of this diferric transferrin reductase may provide a basis for cell differentiation and growth control by retinoic acid.

MATERIALS AND METHODS

3T3 cells (SV/T2, SV40 transformed, and BALB/3T3 non-transformed) were grown under an atmosphere of 5% CO_2 and 95% air at 37°C. The growth medium was a minimal essential medium containing 10% serum, 100 U of penicillin, and 100 μ/ml of streptomycin at pH 7.4. Cells were maintained in a similar medium containing 2% serum (Sun, *et al.*, 1983). Confluent monolayer cultures were then prepared for study by pelleting the trypsinized, suspended cells at 15,000 g. The pellet was diluted with TD-Tris buffer (NaCl 8 g/l, KCl 0.38 g/l, Na_2HPO_4 0.1 g/l, and Trizma base 3 g/l, pH 7.4) to a final concentration of 0.1 g cell wet weight/ml (gww/ml). The harvested cells were in exponential growth phase.

The effect of all trans retinoic acid on cell growth was examined by growing cells in various concentrations of serum with and without the presence of retinoic acid. After two days of incubation at 37°C, cell morphology was examined under the microscope, cells were then harvested, and a cell survival count was immediately taken. Survival was determined by an eosin Y exclusion method as described by Mitchell and Shrigi (1980).

Transmembrane electron transport activity was assayed by measuring the reduction of iron in diferric transferrin by whole cells. The formation of ferrous bathophenanthroline disulfonate was determined according to Avron and Shavit (1963). Absorbance changes between 535 nm and 600 nm were determined in the dual beam mode with the DW2a Aminco spectrophotometer. An extinction coefficient of 17.1 mM^{-1} cm^{-1} was used. The assay mixture in 2.8 ml TD buffer contained 3.4 μM diferric transferrin, 3.3 μM bathophenanthroline disulfonate, and 0.015 gww of cells. Diferric transferrin was obtained from Miles Laboratories. Assay temperature was 37°C. Proton release was performed as described previously (Sun and Crane, 1985).

Transmembrane electron transport activities could also be determined by measuring ferricyanide reduction with intact cells. Ferricyanide reduction by cells were performed in an Aminco DW2a dual beam spectrophotometer equipped with a 37°C temperature-controlled chamber and a magnetic stirrer (Crane, *et al.*, 1982). TD-Tris buffer was used. Absorbance changes were measured in the dual wavelength mode using 420-500 nm. The rates were recorded with a Linear recorder. A millimolar extinction coefficient of 1.0 mM^{-1} cm^{-1} was used for potassium ferricyanide. There is an initial fast rate of ferricyanide reduction by cells for 1-2 min, followed by a steady slower rate which continues for 10 min or longer (Clark, *et al.*, 1981).

The application of flow cytometer to study the cell cycle distribution has been described previously (Krishan, 1975; Stern and Lindmo, 1979). The cell grew for 72 hr. with or without the presence of retinoic acid. The total DNA content of the cells was measured with a fluorescent dye, propidium iodide, which bound to DNA. After treatment of the cells (10^6/ml) with propidium iodide (50 μg/ml in 0.1% sodium citrate) for 2 hr., the treated cells were then injected into the nozzle by a motor-driven syringe. The fluorescence resulting from the dye-DNA complex in each cell was quantitated and displayed as a histogram by a computer.

RESULTS

To reduce impermeable oxidants by cellular internal NADH, a redox system is necessary to carry electrons across the plasma membrane. The use of intact cells, therefore, provides the best assay of transmembrane redox enzyme activity. The reduction of Fe_2Tf by whole cells is measured by the formation of a chelate, ferrous bathophenanthroline disulfonate in the external media (Avron and Shavit, 1963). The effect of retinoic acid on Fe_2Tf reductase of BALB/T2 and SV/T2 cells was examined. The results are seen in Table 1. Very little effect of retinoic

TABLE 1. Effect of retinoic acid on the reduction of diferric transferrin by 3T3 cells.

Concentration of Retinoic Acid	Fe²Tf Reduction (nmoles min^{-1} gww^{-1}) SV/T2 cells	BALB/3T3 cells
None	5.4	12.5
10^{-8}M	5.1	11.2
10^{-7}M	4.9	8.4
10^{-6}M	4.7	6.2
10^{-5}M	4.3	4.1

TABLE 2. Effect of retinoic acid on redox activities of 3T3 cells.

Redox Activities	Addition	Reduction Rate (n moles/min/gww) SVT2 (Transformed)	BALB/3T3 (Non-Transformed)
Diferric Transferrin Reduction	None	2.1	15.5
	Retinoic Acid (1 x 10^{-5}M)	1.8	4.93
Ferricyanide Reduction (Fast Rate)	None	93	168
	Retinoic Acid (1 x 10^{-5}M)	81	24
Ferricyanide Reduction (Slow Rate)	None	15	108
	Retinoic Acid (1 x 10^{-5}M)	18	0

acid is seen with SV/T2 cells. However, retinoic acid gives up to 70% inhibition of reductase activity with BALB/3T3 cells. A similar effect is also observed for ferricyanide reduction by the non-transformed cells (Table 2).

Redox coupled proton release by BALB/3T3 cells is also inhibited by retinoic acid to an extent similar to electron transport (Table 3), whereas proton release induced by Fe_2Tf with SV/T2 cells gives only a ~10% effect of retinoic acid. Instead of inducing proton release, Fe_2Tf induces proton up-take by SV/T2 cells.

The effect of retinoic acid on cell growth was also examined. Significant growth inhibition caused by retinoic acid is shown by BALB/3T3 cultures only. An insignificant effect is seen with SV/T2 cultures (Table 4).

The morphological study shows that retinoic acid induces several interesting features in BALB/3T3 cultures but causes no significant morphological changes in ST/T2 cultures. These interesting features include: 1) induction of gaps among cells; 2) formation of slim shape with tails; and 3) enlargement of cell size in some cells (Figure 1). There are no morphological differences between the untreated cultures of BALB/3T3 and SV/T2 cells.

The study with flow cytometry provides a study of cell cycle distribution through the fluorescence measurement (DNA content). The various phases of the

TABLE 3. Effect of retionic acid on redox induced proton release by 3T3 cells.

Redox Agents	Addition	Rate of H_+ Release (n moles/min/gww) SVT2 (Transformed)	 BALB/3T3 (Non-Transformed)
Diferric Transferrin	None	−166	617
	Retinoic Acid (1 x 10^{-5}M)	−154	221
Potassium Ferricyanide	None	551	904
	Retinoic Acid (1 x 10^{-5}M)	448	147

(−) indicates proton uptake.

TABLE 4. Effect of retinoic acid on the growth of 3T3 cells.

Concentration of Retinoic Acid	No. Cells/25 cm_2 flasks (x 10^{-6}) SV/T2 (Transformed)	 BALB/3T3 (Non-Transformed)
Control	4.36	5.67
10^{-9}	4.25	5.42
10^{-8}	4.13	4.77
10^{-7}	4.12	4.34
10^{-6}	4.0	4.30
10^{-5}	4.16	4.32

cell cycle provided from the fluorescence measurement give an index of the proliferation pattern. It is interesting to compare the cell cycle parameters of BALB/3T3 and SV/T2 cells before and after treatment with retinoic acid (Table 5). SV/T2 cells treated with retinoic acid show a decrease in the percentage of S phase and a significant increase in the percentage of G2/M phase. In contrast, BALB/3T3 cells show a large increase in the percentage of S phase, while the percentage of G2/M phases drops proportionally after retinoic acid treatment. These opposing effects may explain the rapid growth of SV/T2 cells and the slow growth of BALB/3T3 cells, while retinoic acid (1 x 10^{-5} M) is present in cultures.

DISCUSSION

The basis for growth control by transmembrane electron transport is unclear. However, the known effect of this redox activity is the oxidation of cytosolic NADH to increase NAD concentration (Navas, *et al.*, 1986) which can act to regulate inosine monophosphate dehydrogenase, a key enzyme in purine (DNA building block) biosynthesis. Evidence has also shown that this transmembrane redox system is responsive to agents which stimulate cell growth, such as insulin, (Crane, *et al.*, 1982) at the concentration which promotes cell proliferation and is inhibited by antitumor drugs at a concentration which shows killing effects (Crane, *et al.*, 1985; Sun and Crane, 1985). Therefore, it is reasonable to propose

TABLE 5. Effect of retinoic acid on cell cycle parameters.

Cells/Treatment	Cell cycle S (%)	 G^2/M (%)	 G^o/G (%)
BALB/3T3 (control)	27.55	41.47	30.97
BALB/3T3 (plus RA*)	62.45	5.60	31.93
SV/T2 (control)	35.61	16.11	48.27
SV/T2 (plus RA*)	17.15	36.38	56.45

RA* = Retinoic acid (1 x 10^{-5}M).

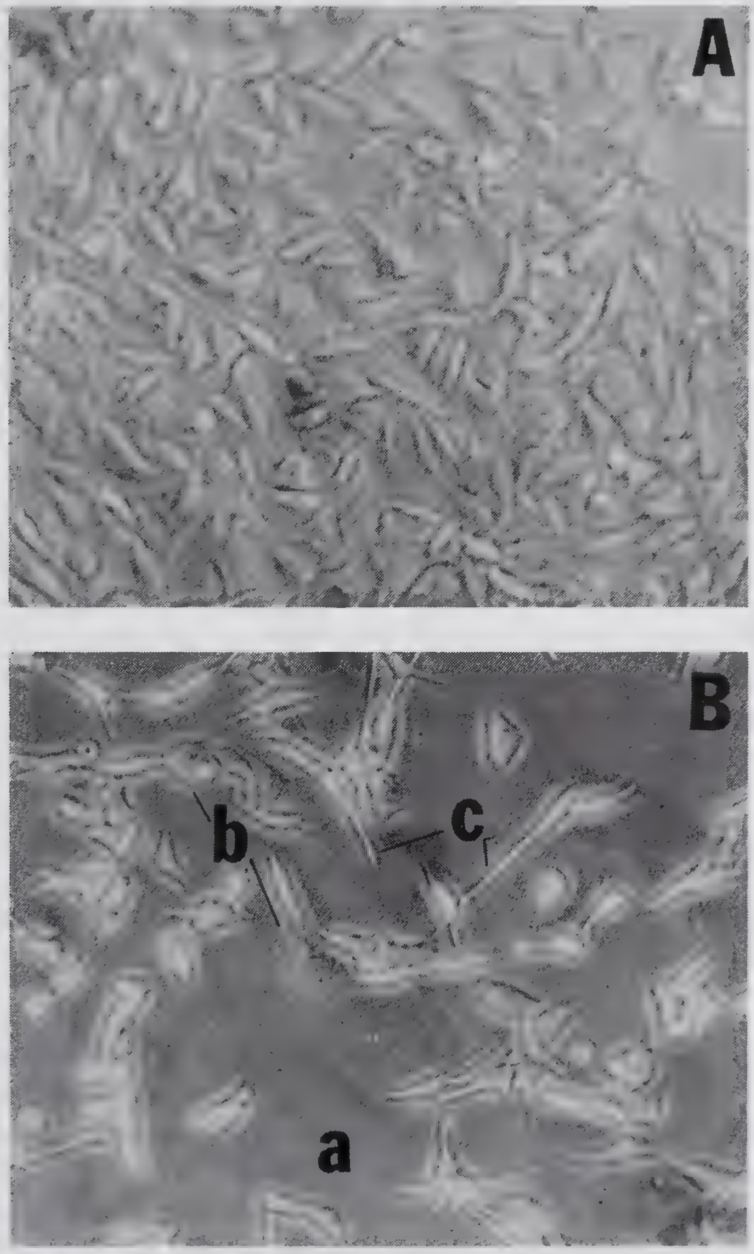

FIGURE 1. Effect of retinoic acid on the morphology of BALB/3T3 cultures: (A) BALB/3T3 controlled cultures; (B) BALB/3T3 treated cultures (a) gapping, (b) enlargement, and (c) tail formation. Treated cells were grown in media containing retinoic acid (10^{-5}M) for 72 hours.

that the control of cell differentiation and growth by retinoic acid may be related to its effect on transplasma membrane redox activities. Data presented in this study, which shows a correlation between morphology, proliferation index, and transplasma-membrane enzyme activity after treatment with retinoic acid, strongly supports the idea.

The difference in sensitivity to retinoic acid between BALB/3T3 cells and SV/T2 cells is similar to that observed by Jetten, *et al.* (1979) in which the inhibition of exponential cell growth and a reduction in saturation density by retinoic acid between transformed and non-transformed mouse fibroblast cells were compared. The *RLA209-15* cell line was established by transforming primary fetal rat hepatocytes with a simian virus 40 (tsA209 virus) that is temperature sensitive for maintenance of transformation. At the nonpermissive temperature (40°C), these cells did not show characteristics of malignant transformation, as they did at the permissive temperature (33°C) but regained the normal differentiated phenotype characterized by an induction of albumin and α-fetoprotein. Under the treatment of retinoic acid, an alteration of the ratio of the functional liver proteins in these cells has been described with a decrease of α-fetoprotein and an increase of albumin production (Chou and Ito, 1984). However, insignificant difference has been observed in cells with transformed phenotype (cell grown at 33°C), for they have very low level of functional liver proteins either with or without the presence of retinoic acid. All these evidences indicate a retinoic acid resistance shown by SV40 viral transformed cells, whereas a strong sensitivity was observed on non-transformed cultures.

A study of retinoic acid on cell cycle parameters indicates that SV/T2 cells show a quick shift of G2/M phases from S phase (Table 5). This may explain why transformed SV/T2 cells are a fast grower and lack cell regulation. In contrast, BALB/3T3 cells show an increase of DNA during the replication phase and a dramatic decline of G2/M phase. The S phase arrest without proceeding to the post-DNA replication phase or mitotic division may explain why the cell size of BALB/3T3 is enlarged, and this is how the alteration of cell morphology (differentiation) is observed on BALB/3T3 cultures. An increase of the relative frequency of myotube-like giant cell formation in rat rhabdomyosarcoma (Gabbert, *et al.*, 1988) and induction of cell flattering and gapping in B16-F10 (lung tumor) cells (Lotan and Lotan, 1980) by retinoic acid have also been described.

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CHEMISTRY

Chair: Ben Nassim
Department of Chemistry
Indiana Univ. Southeast
New Albany, IN 47150

Chair-Elect: Margaret Cavanaugh
Department of Chemistry
St. Mary's College
Notre Dame, IN 46556

ABSTRACTS

RCHDCHDX Compounds as Stereochemical Probes: Avoiding Deuterium Decoupling. Ted T. Ashburn, Simone R. Head, and Paul L. Bock, Department of Chemistry, Ball State University, Muncie, IN 47306.—The use of RCHDCHDX compounds to examine the stereochemistry of reactions involving organic and organometallic compounds has been of somewhat restricted utility because deuterium decoupling is required in order to observe the proton-proton coupling constants which provide the stereochemical information. The MATHCAD simulations described here strongly suggest that the use of resolution enhanced FT-NMR spectra will allow the determination of the appropriate vicinal coupling constants for these compounds without requiring the use of deuterium decoupling.

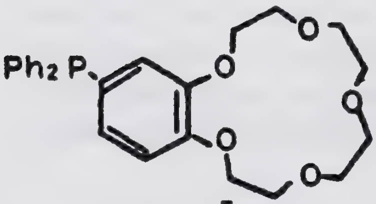
Characterization of a Direct Injection Nebulizer. Thomas W. Avery, Joseph J. Thompson, and Esther R. Surface, Department of Chemistry, Ball State University, Muncie, IN 47306—A direct injection nebulizer (DIN) was constructed and evaluated as an interface for high performance liquid chromatography with inductively coupled plasma-atomic emission spectrometric detection. Detection limits, injection precision and other parameters were nearly identical to literature data for a commercial device, despite the fact that critical steps in the fabrication of the DIN were done in-house. In addition, the nebulizer demonstrated equivalent response for several phosphorous-containing compounds of varying volatility. This uniform response was not observed using a conventional concentric nebulizer with a Scott-type spray chamber.

Technique for Improving Quantification of PPB Level Chloride Determinations in Multicomponent Anion Analysis Using Ion Chromatography with a Pre-concentration Column. Daniel L. Burden and Stanley L. Burden, Chemistry Department, Taylor University, Upland, IN 46989 and AuSable Institute of Environmental Studies, Mancelona, MI 49659.—Chloride ion is particularly troublesome to quantify accurately by ion chromatography when using a pre-concentration column. The limited capacity of the pre-concentration column and competition for sites on this column by more strongly retained ions, such as sulfate, cause severe non-linearity in the calibration curve for chloride. The current procedure for handling this problem is to use three or more standards and fit the PPB vs. area points with a second order least squares polynomial equation. This paper will show that significantly improved accuracy is realized by taking the logarithm of PPB before fitting the calibration points. Results from using this technique on data from simultaneous analysis for PPB level mixtures of chloride, nitrate, phosphate, and sulfate will presented and discussed.

Glucose Test Strips as Peroxide Indicators. R. DALE DELK, CAROL L. WALTERS, CHRISTOPHER YAMAMOTO, and BRUCE N. STORHOFF, Ball State University, Muncie, IN 47306.—Three types of commercially available test strips of the types used to monitor glucose levels in blood or urine have been evaluated as indicators for peroxides in aqueous and nonaqueous solutions. For aqueous solutions, the minimum detectable quantities of hydrogen peroxide for Diastix^R, Clinistix^R, and Chemstrip^R reagent strips were found to be 1.5 mg/dl, 0.2 mg/dl, and 0.8 mg/dl, respectively. These strips were also found to change color in response to the presence of benzoyl peroxide in ether. The Diastix^R, for example, responded to levels of this peroxide which were greater than 0.6 mg/dl.

Interactions of Iron and Copper with Some Sulfur Oxyanions. KRIS DHAWALE, I.U. East, 2325 Chester Blvd., Richmond, IN 47374-9979.—Aqueous corrosion of iron, copper and their alloys in the presence of sulfur oxyanions is under investigation in our laboratory. This paper deals with the use of Ferrozine and Bathocuproine reagents for the determination of Fe^{2+} and Cu^{1+} ions during corrosion of those metals, and some copper base alloys were also tested in the presence of sulfite, hydrosulfite, tetrathionate, thiosulfate and metabisulfite. The metals are exposed to aqueous solutions of sodium salts of sulfur oxyanions. Then filtered solutions are assayed for Fe^{2+} and Cu^{1+} using the Spectronic 20 for quantitative determination. This work was undertaken to see if these assays can be used to determine the rate of dissolution of the metals. In the absence of any other precise analytical techniques, such assays can give a good estimate of the rate of dissolution.

Phosphine-Functionalized Crown Ethers. JAMES E. FRITZ, MARY KAY NEEB, and BRUCE N. STORHOFF, Ball State University, Muncie IN 47306.—Both of the phosphine-functionalized crown ethers shown below have been obtained in modest yields from readily available starting materials. The precursor of II, the corresponding amine, was isolated in modest yield from HN[(CH$_2$)$_2$O(CH$_2$)$_2$OH]$_2$, α, α'-dibromo-o-xylene, and potassium-t-butoxide in t-butanol. Reaction of the amine with diphenylphosphine and aqueous formaldehyde provided II. Compound I was obtained from benzo-15-crown-5 *via* a reaction sequence which involved bromination, Li-Br exchange and attack on ClPPh$_2$. The spectroscopic and P-binding properties of these ligands will be discussed.



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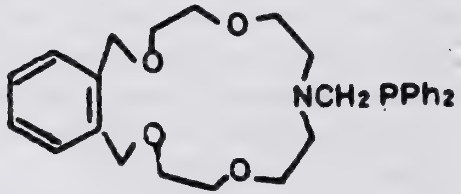
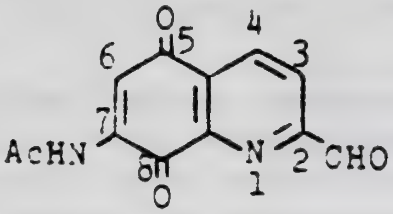


II

Synthesis of 7-Acetamido-2-formylquinoline-5,8-dione. ZHENGXIANG GU, MACKLIN B. ARNOLD, ARON C. SOUSA, and MOHAMMAD BEHFOROUZ, Department of Chemistry, Ball State University, Muncie, IN 47306.—The title aldehyde (1) an intermediate in the total synthesis of antibiotic antitumor agent lavendamycin (2) was prepared through the Diels-Alder reaction of a 1,3 azadiene with a bromoquinone followed by oxidation. Compound 1 was also prepared by nitration of 8-hydroxy-2-methylquinoline followed by reduction, acetylation and oxidation.



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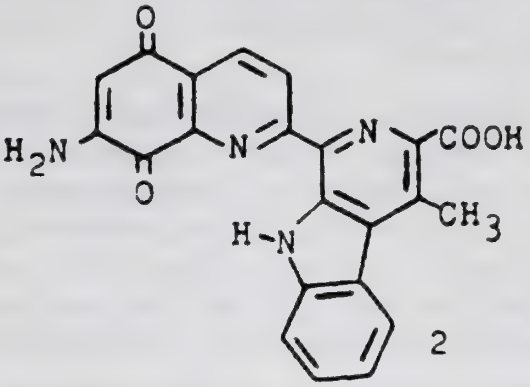

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The Nickel (II)-Dimethylglyoxime Complex: A New Use for an Old Compound. A.J.C.L. HOGARTH, Ross Laboratories, Department 417, 625 Cleveland Avenue, Columbus, Ohio 43216.—Typically, in undergraduate laboratories, the gravimetric determination of nickel is used to demonstrate precipitation from homogeneous solution. The strawberry-red nickel (II)-dimethylglyoxime complex produced is easily dried and weighed, it is heat stable to at least 121 C, it resists atmospheric oxidation and it is analytically pure. The last property has to be true otherwise its use as a quantitative measure of nickel would be of little value. With all these desirable properties, those of a chemical standard material, the complex is normally thrown away after many undergraduates have labored to produce it, and little thought is given to using it. This paper explores a possible use, that of a standard material against which to standardize solutions of EDTA.

A Quest for Flashy Crowns: Progress on a "Clip-On" Approach. SUZY POPE, M. CATHERINE COSBY, AND LYNN R. SOUSA, Department of Chemistry, Ball State University, Muncie, IN 47306.—A long-time goal of our research program is the invention of compounds that will signal the amount of potassium ion present in solution by emitting fluorescence. One scheme we are investigating uses a crown ether compound that has a fluorescent chromophore on one edge of the crown ring and a quencher of fluorescence on the other edge. In the absence of K^+, the crown ring is flexible, and the quencher can effectively stop the fluorescence of the chromophore. However, when K^+ is present, the crown ether complexes the ion and the crown ring is stiffened as a result. This stiffening separates the chromophore from the quencher and leads to an increase in fluorescence. To speed the research process, we are synthesizing a crown ether key intermedite with two different reactive sites. A number of different fluorescent chromophore-quencher pairs could be readily prepared from this "clip-on" crown ether. Progress on the synthesis will be described.

Molar Refractions of Metal Ions in Complexes. EUGENE P. SCHWARTZ, Department of Chemistry, DePauw University, Greencastle, IN 46135.—Molar refractions (electronic polarizations) of a number of neutral complexes in benzene were measured with a differential refractometer and calculated by the method of Halverstadt and Kumler. Ring refractions were obtained from the beryllium complexes. If the central metal has none or has ten *d* electrons (Al^{+3}, Sc^{+3}, Ga^{+3}) the apparent molar refraction of the central metal is smaller in the dipivaloyl-methane (2,2,6,6-tetramethyl-3,5-heptanedione) complex than in the acetylacetone (2,4-pentanedione) complex, whereas these ligands show little effect for the other transition elements studied (Cr^{+3}, Mn^{+3}, Fe^{+3}, Co^{+3}). The apparent molar refraction of the metal when complexed with dibenzoylmethane (1,3-diphenyl-1,3-propanedione) is much smaller than when complexed with acetylacetone for all of the metals studied.

Determination of Molar Absorptivities and Formation Constants for Complexes of Copper (II) and Cobalt (II) with 3-Aminopyridine. JOSEPH R. SIEFKER AND RIE-WHUN GIHL, Department of Chemistry, Indiana State University, Terre Haute, IN 47809—The coordination of some transition metal ions with 3-aminopyridine was studied. Spectrophotometric data were obtained with aqueous solutions. The molar absorptivities and formation constants were calculated with a computer program using a CDC Cyber 171 computer.

Speciation of Cisplatin and Related Compounds by High Performance Liquid Chromatography With ICP-AES Detection. JEFFREY J. STADICK, JOSEPH J. THOMPSON, and BRUCE N. STORHOFF, Department of Chemistry, Ball State University, Muncie, IN 47306—Cisplatin (a drug used in cancer therapy), transplatin and their hydrolysis products were separated on a carbohydrate column and detected at ppb levels by an inductively coupled plasma-atomic emission spectrometer. A direct injection nebulizer comprised the interface between column and spectrometer. The method is evaluated as a means of monitoring levels of this drug and its degradation products in body fluids.

The Identification of Superoxide Dismutase in Human Serum Using Polyacrylamide Gel Electrophoresis. EUGENE S. WAGNER, Center for Medical Education, Ball State University, Muncie, IN 47306.—During the past 30 years biochemists have isolated types of molecules known as free radicals which purloin electrons from other molecules and disrupt healthy cell function. Restoration of normal cell function can be accomplished by the interaction of body-produced enzymes called antioxidants which neutralize these free radical toxins. If the body does not produce enough of these antioxidant enzymes naturally because of diet, disease, trauma, chemicals, environment, or age, this cellular underproduction must be provided by other sources. One such source is wheat sprout which is rich in Superoxide Dismutase, SOD, a potent antioxidant enzyme. The claims of many in the health food industry that dietary supplementation of SOD increases erythrocyte levels of SOD prompted this study which outlines a procedure, employing polyacrylamide gel electrophoresis, to measure the presence of SOD in human serum.

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ELECTROSPRAY FOR SURFACE DERIVATIZATIONS IN CHROMATOGRAPHY/SIMS

MONTE W. COLLINS and KENNETH L. BUSCH
School of Chemistry and Biochemistry
Georgia Institute of Technology
Atlanta, Georgia 30332

INTRODUCTION

Secondary ion mass spectrometry (SIMS) has become a valuable technique for the direct imaging analysis of thin-layer chromatograms (TLC); TLC/SIMS has been demonstrated for many classes of compounds including peptides (Dunphy and Busch, 1988; Stanley and Busch, 1989), porphyrins (Dean and Busch, 1989), bile acids (Dunphy and Busch, 1990), and steroids (Brown and Busch, 1989). The developed intact chromatogram is placed directly on a platform in the source chamber of a custom-built SIMS mass spectrometer (Fiola, *et al.,* 1986) and is moved in the x and y directions by piezoelectric crystal translator stages. Because the developed spots on the chromatogram can be moved into and out of the focus of the primary ion beam, preferential or multi-spot analysis as well as chromatographic imaging is possible.

In chromatography/SIMS, as in any liquid SIMS technique, ion yields for compounds already in the ionic state are greatly increased compared to the ion yields for non-charged species. Normally, ionization of neutral molecules in liquid SIMS is achieved by protonation of the analyte to create the $(M+H)^+$ species. However, this is a relatively inefficient process; in general, only about five percent of all neutrals sputtered by the energetic primary ion beam are ionized as $(M+H)^+$ (Fenselau and Cotter, 1987). Derivatization strategies in which a localized charge is placed on a molecule of the compound of interest have been developed that increase sensitivity and lower detection limits in the chromatography/SIMS technique (Brown and Busch, 1989; Duffin and Busch, in press).

Brown and Busch (1989) have developed a derivatization strategy for post-derivatizations on TLC plates. The reaction scheme (Figure 1) involves the reaction of a carbonyl functional group from an aldehyde or a ketone with Girard's T reagent, creating a localized charge on the newly derivatized compound. The methodology for the derivatization involves suspending the developed TLC plate in a developing chamber a few cm above a solution containing the Girard's T reagent, methanol, and an acid catalyst, usually acetic acid. The developing chamber is then placed into an oven at a temperature corresponding to the boiling point of methanol (60° C). Vapors of the solution react with the analytes on the surface of the TLC plate without increasing the spot size or decreasing the resolution. However, since the derivatizations are carried out in the vapor phase, this method works only for derivatizing reagents that are relatively volatile. A method for surface derivatization involving electrospray that is capable of derivatizations using non-volatile as well as volatile reagents is described in this paper.

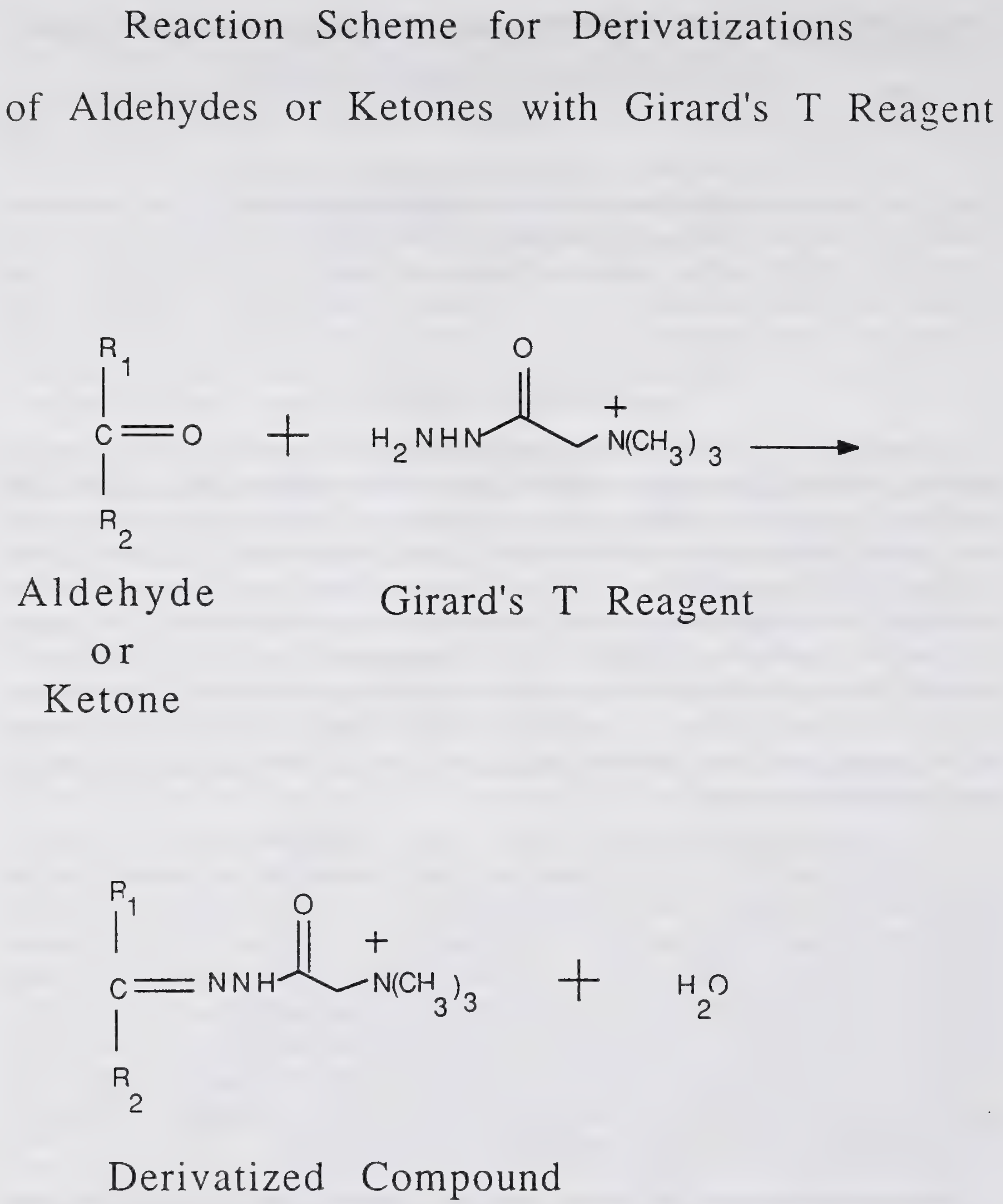

FIGURE 1. Reaction scheme for the derivatization of aldehydes or ketones with Girard's T reagent.

EXPERIMENTAL

Positive ion mass spectra were obtained with a custom built mass spectrometer (Fiola, *et al.*, 1986) based on a Extrel quadrupole mass analyzer. A 6 keV argon atom beam was used as the primary beam with a current of 4 mA. Results are the same if a cesium ion beam is used as the primary particle source. Chamber pressure was constant at 8 x 10^{-5} torr.

A suitable solvent system for the electrospray deposition was found to be methanol:water (75:25) in which 0.5 µg of Girard's T reagent was dissolved. A sample size of 5 µl of a 5 µg/µl solution of the steroid was spotted onto an aluminum-backed TLC plate. The Girard's T reagent was deposited over the spots

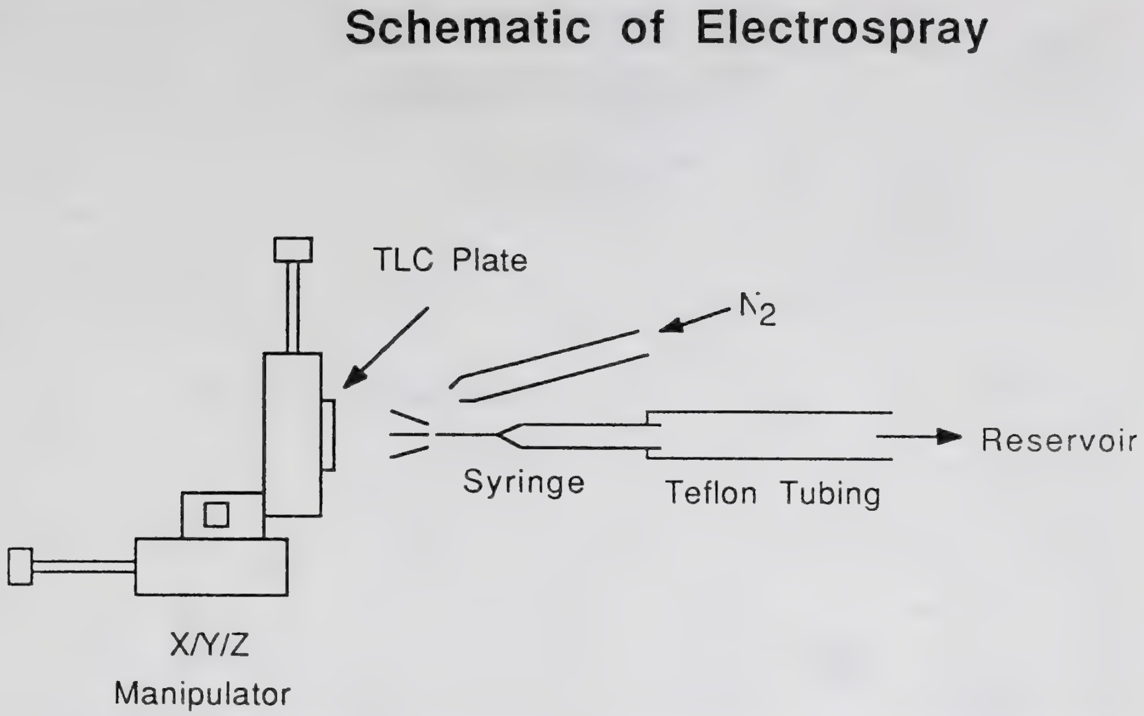

FIGURE 2. Schematic of electrospray for uniform depositions of solid materials.

by means of electrospray (see below). The plate was then suspended in a developing chamber above a solution bath containing methanol and an acetic acid catalyst. The developing chamber was then placed in an oven at 60° C so that acetic acid vapors could come into contact with the analyte and the Girard's T reagent in order to catalyze the final steps of the reaction. The plate was then placed directly in the ion source of the mass spectrometer for subsequent mass analysis.

INSTRUMENTATION

An electrospray apparatus (Figure 2) was constructed after the design developed by McNeal and Macfarlane (1979), who used the uniform deposition capabilities of electrospray to deposit samples in thin films onto foils for use in their plasma desorption mass spectrometer. The electrospray cell consists of a hypodermic needle acting as the anode or delivery electrode. The cathode, where the deposition takes place, is actually the target stage of an xyz manipulator set at ground potential. A reservoir is needed to feed the hypodermic needle, while capillary forces are responsible for the continuous flow of solvent. A high voltage power supply (0-5 kV, 3 mA) is connected to the hypodermic needle through a 50 megaohm resistor that eliminates high current and prevents voltage breakdown. The electrospray apparatus is housed in a Lucite box to minimize turbulence between the anode and the cathode, to provide a controlled environment, and to provide for safe working conditions in everyday use.

RESULTS AND DISCUSSION

Deposition of the derivatizing reagent onto the surface of the chromatogram is accomplished by placing a high voltage (3-5 kV) on the anode relative to the cathode. As a droplet forms on the tip of the needle, the high voltage overcomes the surface tension of the solvent, and the solution is dispersed into tiny charged particles. As the charged droplets travel from the anode to the cathode, the solvent

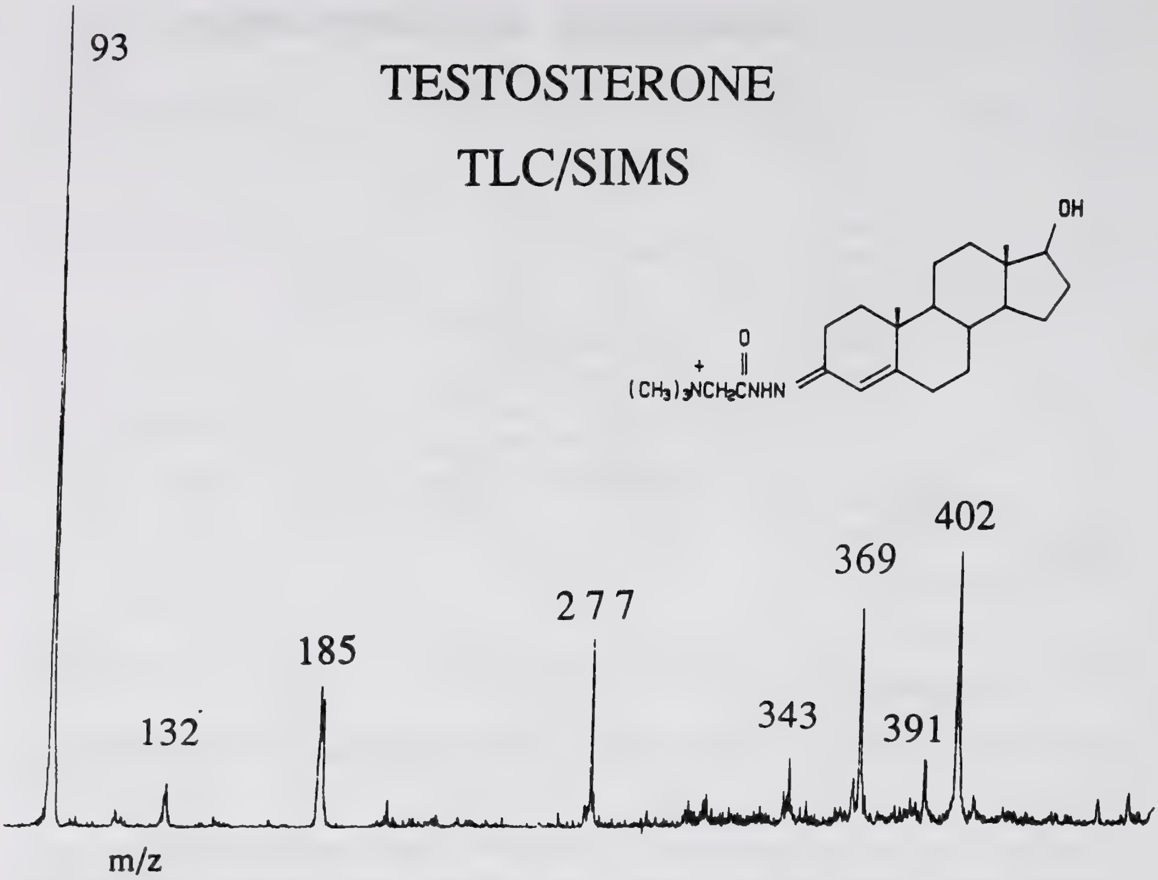

FIGURE 3. Positive ion mass spectrum of the Girard's T derivative of testosterone.

evaporates because of its high vapor pressure and by absorbing energy from collisions with atmospheric particles. The solute residue of each droplet, in this case the derivatizing reagent, is therefore deposited on the cathode.

In the method developed by Brown and Busch (1989), the derivatizing agent must be volatile for the transfer of the derivatizing reagent in the vapor phase to the TLC plate for subsequent reactions. Utilization of electrospray for transfer of the derivatizing reagent directly onto the TLC plate eliminates the need for the volatility of the reagent. Volatilization is required only to place the acetic acid, acting as the catalyst, into contact with the surface for reaction with the derivatizing reagent already on the TLC plate. If the reaction scheme demands multi-step reactions, each volatile *or* non-volatile reagent can be deposited with relative ease without harm to the reagents or analyte. With electrospray, no solvent actually comes in contact with the plate. Since the solvent evaporates in flight to the cathode, the possibility of spot spreading is eliminated. The vapor phase deposition of the acetic acid has no effect on the chromatographic resolution.

The positive ion mass spectra of derivatized testosterone and androsterone confirm the positive outcome of the derivatization strategy using electrospray. Figure 3 shows the mass spectrum of derivatized testosterone, which has a molecular weight of 402. A relatively abundant peak at 402 daltons corresponds to the derivatized testosterone/Girard's T intact cation. A characteristic fragment ion exists at m/z 343, which results from the loss of a neutral trimethylamine. Ions at m/z 93, 185, and 369 correspond to the protonated glycerol ion, the dimer of glycerol, and the trimer of glycerol, respectively. The ion at m/z 132 shows an unreacted portion of the Girard's T cation on the plate.

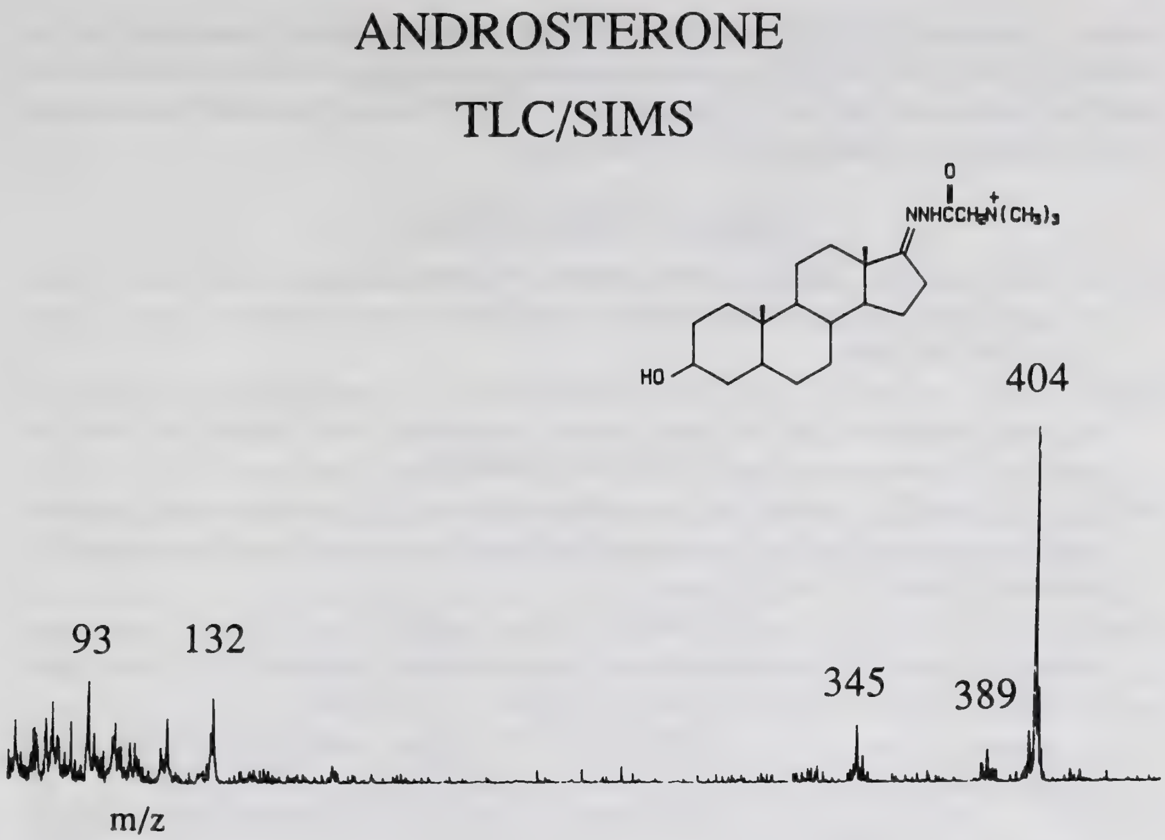

FIGURE 4. Positive ion mass spectrum of Girard's T derivative of androsterone.

Derivatized androsterone also gives a characteristic mass spectrum shown in Figure 4. The peak at 404 daltons corresponds to the intact cation of the androsterone/Girard's T derivatized compound. The loss of trimethylamine gives rise to the ion at m/z 345. Again, unreacted Girard's T is evidenced by the low abundance of the ion at m/z 132.

These initial experiments indicate the utility of the electrospray method for the derivatization of aldehydes or ketones with Girard's T reagent. However, this method has an endless supply of applications for derivatizations in planar chromatography for the purpose of detection by mass spectrometry. Many existing derivatization strategies may be modified so that deposition of the reagents onto surfaces with electrospray methods can be used. For example, analytical chemists use trypsin and cyanogen bromide in order to cleave large peptides (themselves out of the mass range of quadruple instrumentation) into characteristic and smaller fragments. These smaller compounds produce ions of lesser mass within the mass range of the instrument. The electrospray method might be particularly advantageous with multiple cleavages of biomolecules separated by TLC or electrophoresis.

CONCLUSION

Electrospray has proven to be an effective method for depositing non-volatile as well as volatile derivatizing reagents for the purpose of surface derivatizations in chromatography/SIMS. Girard's T was shown to be successful in initial experiments. The ease of the experiment leads one to believe that this method can be effective for many derivatization strategies involving planar chromatography.

Solvent evaporation prior to deposition preserves the spatial resolution of the chromatogram. The newly charged compounds provide higher ion yields lowering detection limits and bettering sensitivity, which enhances the effectiveness and utility of the chromatography/SIMS technique.

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SECONDARY ION MASS SPECTRA FOR IODONIUM SALTS

H.H. SCHURZ and K.L. BUSCH
School of Chemistry and Biochemistry
Georgia Institute of Technology
Atlanta, Georgia 30332

INTRODUCTION

Secondary ion mass spectrometry (SIMS) is ideal for measuring mass spectra for most nonvolatile organic onium salts. In SIMS, an energetic primary ion beam is directed at a sample surface. In liquid SIMS, the sample is dissolved in a vacuum-compatible liquid matrix. In these examples, the samples are dissolved in a glycerol matrix. Upon impacting the surface of the glycerol/analyte solution, the primary ion energy is transferred via a collision cascade to atoms and molecules at the surface lattice. The energy can eject neutral particles, ions, electrons, and photons into the vacuum. Ions are drawn away from the surface by an extraction potential, and mass is analyzed by a quadrupole mass analyzer.

Previous work has shown that SIMS produces good quality mass spectra for iodonium salts (Duffin and Busch, 1986), containing abundant signals for the intact cation and some degree of structurally informative fragmentation. The compounds of interest in this study are the diaryliodonium salts. These compounds are particularly useful as photocatalysts of cationic polymerizations (Crivello and Lam, 1977). Diaryliodonium salts possessing complex metal halide anions photoinitiate the cationic polymerizations of a wide variety of monomers, including olefins, cyclic ethers, cyclic sulfides, cyclic acetals, and lactones. The majority of the polymers produced by photocatalysis of a diaryliodonium salt with a monomer are used as coatings.

In addition to interpretation of the mass spectra themselves, this paper describes the results of some calculations of ion structures for these salts. Specifically, previous work had noted occurrence of fragment ions corresponding to loss of iodine from the intact cations of some iodonium salt. The purpose of this study was to establish the geometry of the iodonium cation to ascertain if such a loss was reasonable. The computational program utilized in the study of some of these salts in available from the Quantum Chemistry Program Exchange located at Indiana University. The program, MOPAC, is a general purpose semiempirical molecular orbital package for the study of chemical structures and reactions (Stewart and Seiler, no date). The software is itself a combination of programs. The semi-empirical Hamiltonian AM1 is used in the electronic portion of the calculations to obtain molecular orbitals, heats of formation, and its derivatives with respect to the molecular geometry. Using the results obtained, MOPAC will further calculate the vibronic spectra, thermodynamic quantities, isotopic substitution effects, and force constants for molecules, radicals, ions, and polymers. The quantities to be examined here are the bond lengths and angles for the iodonium cations.

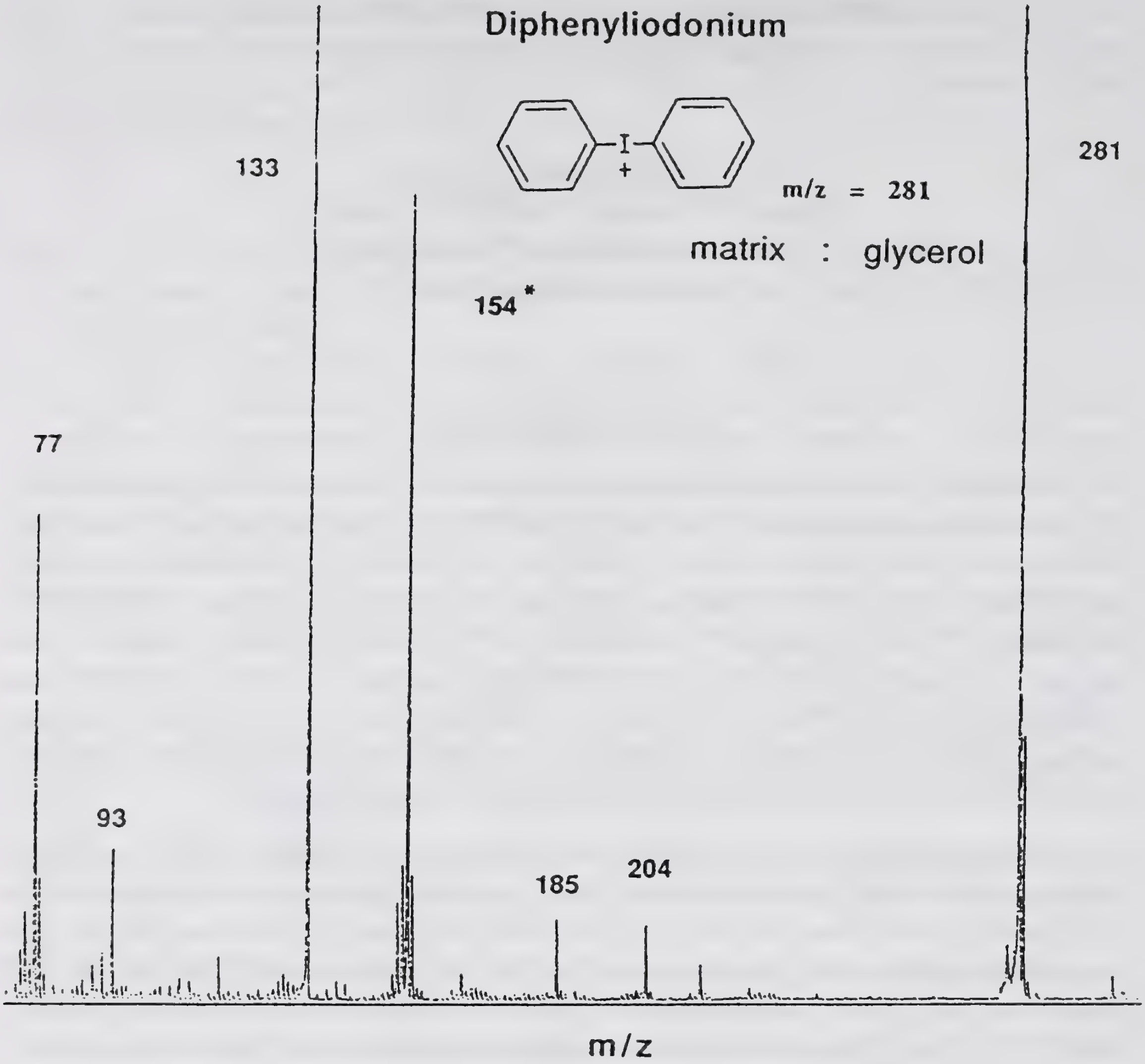

FIGURE 1. SIMS spectrum of diphenyliodonium arsenic hexafluoride.

EXPERIMENTAL

Samples were prepared by dissolution of 1-10 micrograms of each iodonium salt into 10 to 20 microliters of glycerol. The spectra were acquired on a modified Extrel C-50 quadrupole secondary ion mass analyzer (Fiola, *et al.,* 1986). A thermionic cesium source was used for production of the primary cesium ions at a potential of 8 keV. Pressure in the chamber was maintained at approximately 10^{-5} torr. The symmetrical salts studied were diphenyliodonium, 4,4'-dimethyldiphenyliodonium, 2,3,2,',3'-tetramethyldiphenyliodonium, and 4,4'-ditertbutyldiphenyliodonium salts. The asymmetrical salts studied were 4-methoxydiphenyliodonium, 4-propanoic-2-oxyphenyl (phenyl) iodonium, and hexadecyloxyphenyl (phenyl) iodonium salts. Counter ions varied with the salt but were typically arsenic hexafluoride, phosphorous hexafluoride, and the tosylate ion.

Calculations of the iodonium salts were performed with MOPAC, a molecular mechanics program run on a VAX computer. Comparisons of the lengths of the carbon to iodine bonds, the bond angles between the substituted phenyl rings and the iodine, and also the charge of the iodine were initially considered in the calculations.

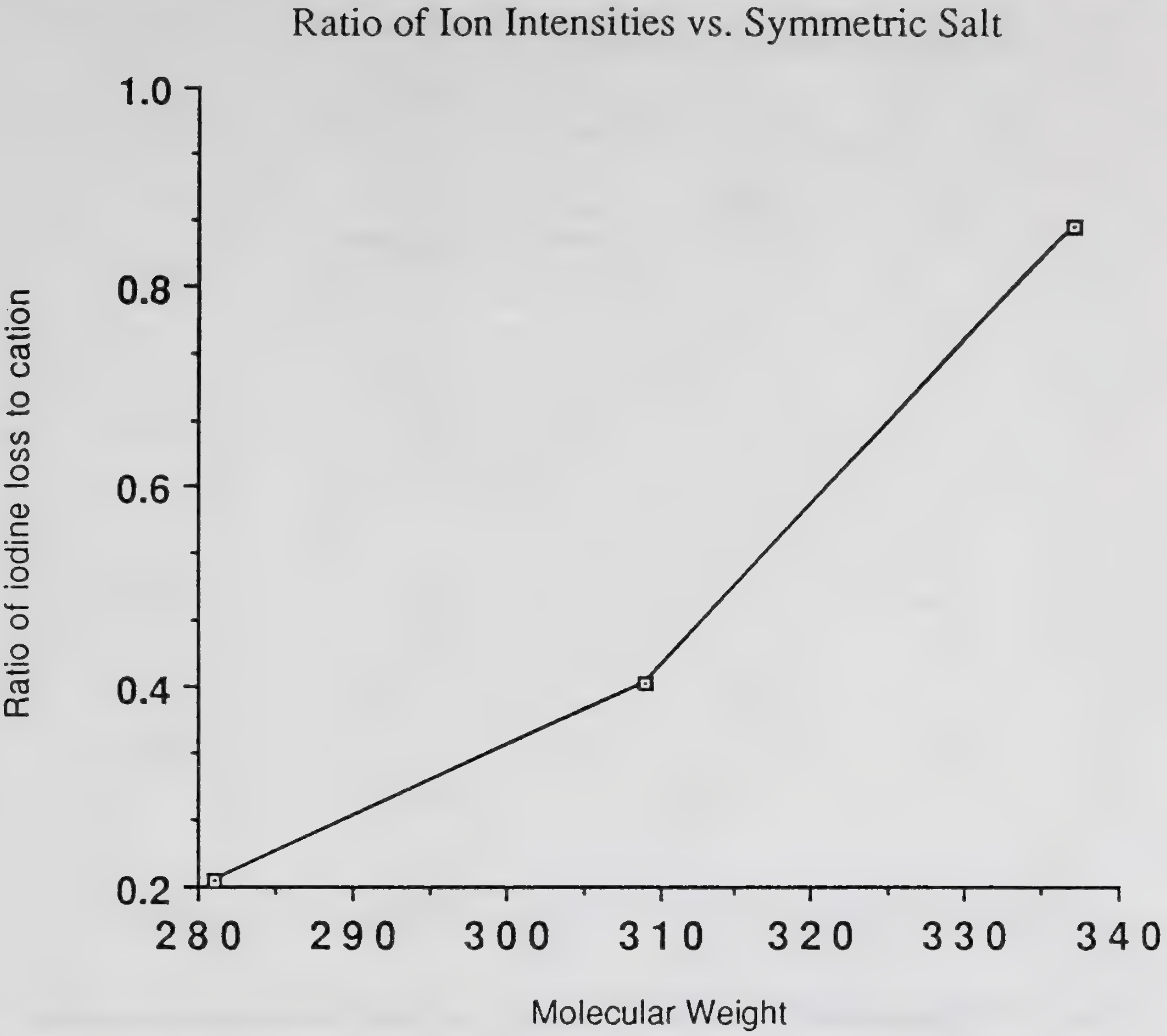

FIGURE 2. Plot of the ratio of ion intensities versus the molecular weight of symmetric iodonium salts.

RESULTS AND DISCUSSION

The positive ion SIMS mass spectrum of diphenyliodonium arsenic hexafluoride is representative of the symmetrical iodonium salts (Figure 1). The base peak corresponds to the intact cation for the salt at m/z 281. The loss of atomic iodine is evident by formation of the fragment ion at m/z 154. Additional fragmentation of the cation includes loss of a phenyl group to yield an ion at m/z 204. Conversely, a peak at m/z 77 is identified as the phenyl group. The glycerol ions $(M+H^+)$ and $(2M+H^+)$ are seen at m/z 93 and m/z 185, respectively. The large peak at m/z 133 is Cs^+ from the primary beam. The mass spectra of the other symmetrical iodonium salts studied also show an intense peak for the intact cation. Loss of atomic iodine from the intact cation is seen in all of the mass spectra, with the exception of 4,4'-di-tert-butyldiphenyliodonium tosylate. If the ratio of the peak intensity for the fragment ion resulting from the loss of iodine to the peak intensity of the cation is plotted versus the molecular weight of the salt, a general increase of the ratio with increasing molecular weight is noted (Figure 2). Calculations with MOPAC indicate an increase in the bond length as well as the bond angle between the two phenyl carbons and the iodine with increasing molecular weight. It is suspected that this increase in bond angle and length can facilitate bond formation at the ortho positions of the two phenyl groups

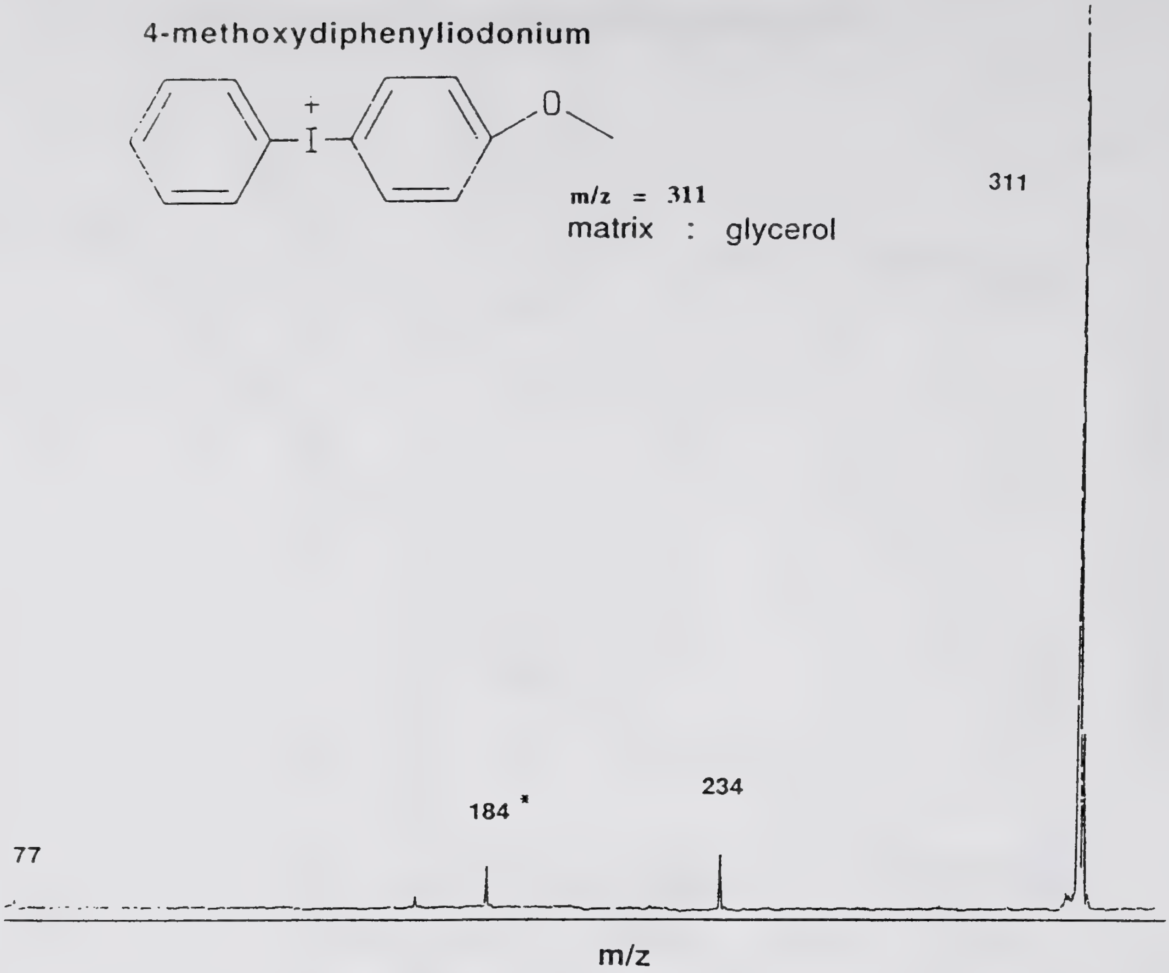

FIGURE 3. SIMS spectrum of 4-methoxydiphenyliodonium phosphorous hexafluoride.

simultaneously with bond breakage between the iodine and the two phenyl groups. This results in an ejection of the iodine from the molecule to produce the "biphenyl" ion seen in the spectra.

The loss of iodine is not evident in the postitive ion SIMS mass spectrum of 4,4'-di-tert-butyldiphenyliodonium tosylate. The lack of this fragment ion can be explained by steric hindrance of the t-butyl groups present in the position para to the iodine bond. According to MOPAC calculations, there is now a decrease in the bond lengths but an increase in the bond angles. This makes it more difficult for the phenyl groups to come close enough for bond formation at the ortho position.

As in the mass spectra of the symmetrical salts, loss of atomic iodine is also seen in the mass spectra of the asymmetrical salts. As an example, the mass spectrum of 4-methoxydiphenyliodonium phosphorous hexafluoride (Figure 3) gives an intense peak corresponding to the intact cation at m/z 311. The loss of iodine produces the fragment ion at m/z 184; the abundance of this ion is rather small. Loss of a phenyl group produces the fragment ion at m/z 234, and the phenyl ion itself is detected at m/z 77. The asymmetrical salts seem to exhibit a trend for iodine loss opposite to that measured for the symmetrical salts. When the ratio of ion abundances for the ion generated by iodine loss to the cation abundances is plotted against the molecular weight, a **decrease** in the degree of

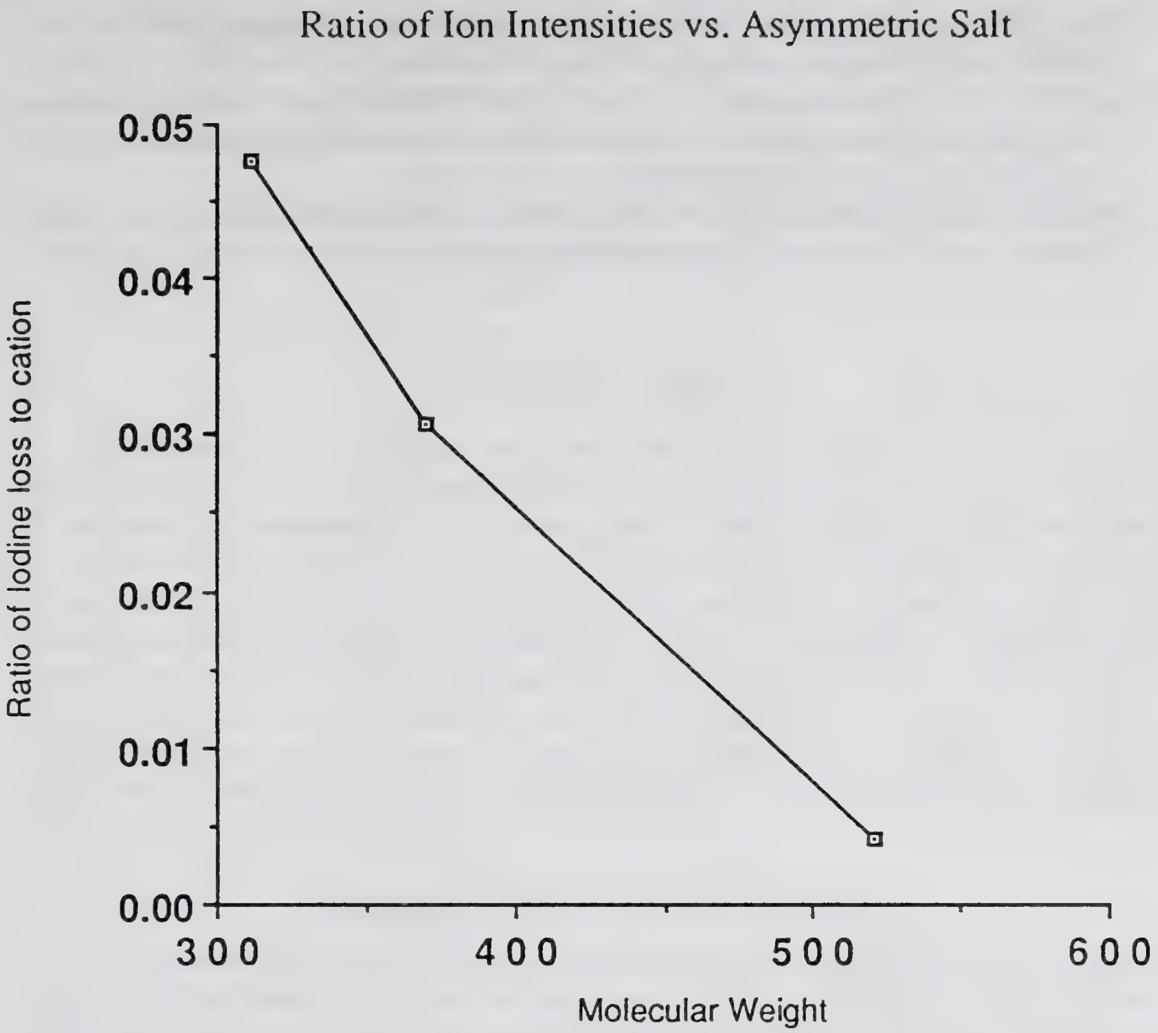

FIGURE 4. Plot of the ratio of ion intensities versus the molecular weight of the asymmetric salts.

fragmentation is seen (Figure 4). Increased molecular weight correlates with increased complexity in structure, preventing the bending of the ion necessary for iodine loss. Further calculations and examples are being studied to determine the generality of this conclusion.

CONCLUSIONS

The mass spectra of iodonium salts are easily measured with secondary ion mass spectrometry. Loss of atomic iodine is characteristic in many of the spectra. Calculations performed with molecular mechanics programs suggest that a bent structure for the ion leads most easily to this loss.

ACKNOWLEDGMENTS

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MODELING A BIOCHEMICAL OSCILLATOR

Curtis G. Steinmetz, Raima Larter, and Baltazar D. Aguda
Department of Chemistry
Indiana University - Purdue University at Indianapolis
Indianapolis, IN 46202

INTRODUCTION

Three kinds of oscillations have been observed in the peroxidase-oxidase reaction : simple, chaotic, and bursting (Olsen and Degn, 1977; see Fig. 1). A model of this reaction, proposed by Degn, Olsen, and Perram (1979), displays these kinds of oscillations in addition to what we call complex oscillations. Using a combination of numerical simulation and bifurcation analysis, our group is attempting to systematically analyze the progression of behavior that leads from stable steady states through simple and complex oscillations to chaos in the Degn-Olsen-Perram (DOP) model. We want to be able to predict where (i.e., at what rate constants) a given behavior (in particular, chaos) will be found in the model. This should aid in the understanding of the peroxidase-oxidase reaction and in the design of future experiments.

THE REACTION AND THE MODEL

Horseradish peroxidase catalyzes the oxidation of NADH by molecular oxygen in the reaction known as the peroxidase-oxidase (PO) reaction. The PO reaction is oscillatory in a semi-open, well-stirred system at acidic pH (pH 5.6 is commonly used). The semi-open system must have: 1) a constant, slow inflow of NADH (about 10 μL/hour); and 2) a constant supply of gaseous O_2 over the system (Degn, *et al.,* 1979). Oscillations occur over a variety of enzyme concentrations in the μM range. As can be seen in Figure 1, varying the enzyme concentration yields three different kinds of oscillations : 1) simple oscillations with a single amplitude (Fig. 1a); 2) chaotic oscillations with random mixtures of varying amplitudes (Fig. 1b); and 3) bursting oscillations with distinct quiet and active phases (Fig. 1c). In this paper, the transition from simple oscillations to chaos will be discussed. In another study (Aguda, *et al.,* 1989), bursting oscillations were discussed.

The DOP model was proposed in 1979 to account for the oscillations and other behavior found in the PO reaction. This model involves four species (O_2, NADH, and two intermediates) in an eight step mechanism and consists of the associated mass action kinetic equations (Figure 2). This model was studied by solving the system of four ordinary differential equations on a VAX8800 computer using an implementation of the Runge-Kutta-Verner method (IMSL routine DIVPRK).

The DOP model yields results qualitatively similar to those seen experimentally, and decreasing the rate constant k_1 controls the kind of oscillation observed much as decreasing the enzyme concentration does in the experimental system (Figure 3). The oscillations of mixed amplitude in the DOP model (e.g., Figure 3b), however, are not necessarily chaotic but sometimes have a definite, periodic pattern of large and small amplitudes. This type of oscillation is referred to as a "complex oscillation." The repeating patterns in complex oscillations are conveniently represented by the notation L^S, where L is the number of large amplitude

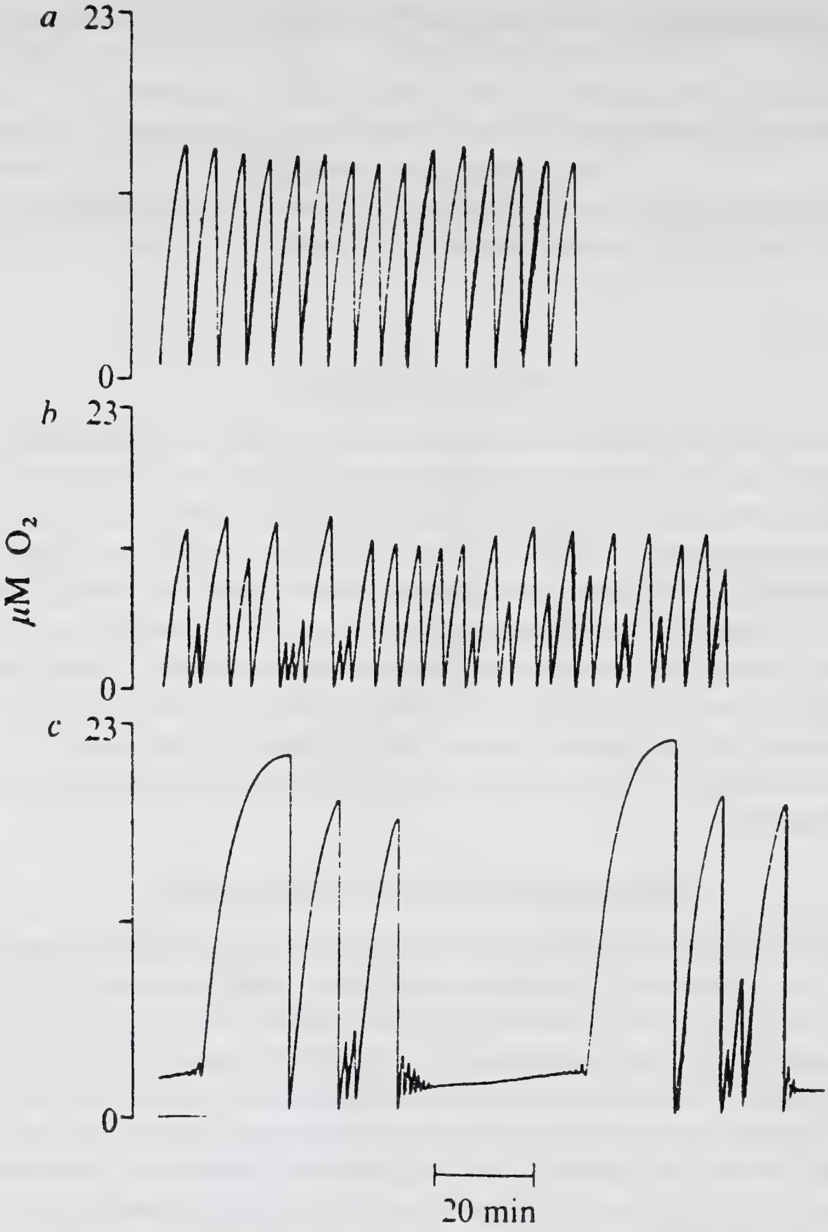

FIGURE 1. Experimental data from the peroxidase-oxidase reaction. The concentration of O_2 was measured with a Clark electrode. The shape of the oscillations was controlled by the concentration of the enzyme horseradish peroxidase. The enzyme concentrations were: a) 0.9 μM; b) 0.55 μM; and c) 0.45 μM.

oscillations, and S is the number of small amplitude oscillations. For example, the repeating pattern in Figure 3b is (4^2 3^3 4^4; this pattern has been confirmed with much longer calculations than the one shown). Complex oscillations have not yet been observed experimentally in the PO reaction; only *random* or *chaotic* mixtures of amplitudes have been seen experimentally, as in Figure 1b. The chaotic states seen in the DOP model occur at parameter values near those yielding complex oscillations (Larter, *et al.*, 1988), and these two types of behavior may be intimately related.

PHASE PORTRAITS AND BIFURCATIONS

Figures 1 and 3 are examples of time series. A time series represents a dynamical (time dependent) system by showing how one of the dependent variables changes with the independent variable, time. An alternative representation of

Degn-Olsen-Perram Model

Mechanism:

$$A + B + X \xrightarrow{k_1} 2X \qquad Y \xrightarrow{k_5} Q$$

$$2X \xrightarrow{k_2} 2Y \qquad X_0 \xrightarrow{k_6'} X$$

$$A + B + Y \xrightarrow{k_3} 2X \qquad A_0 \underset{k_{-7}}{\overset{k_7'}{\rightleftharpoons}} A$$

$$X \xrightarrow{k_4} P \qquad B_0 \xrightarrow{k_8'} B$$

Kinetic Equations:

$$\dot{A} = -k_1ABX-k_3ABY+k_7-k_{-7}A$$

$$\dot{B} = -k_1ABX-k_3ABY+k_8$$

$$\dot{X} = k_1ABX-2k_2X^2+2k_3ABY-k_4X+k_6$$

$$\dot{Y} = -k_3ABY+2k_2X^2-k_5Y$$

Where $k_6 = k_6'X_0$, $k_7 = k_7'A_0$, and $k_8 = k_8'B_0$, and A_0, B_0 and X_0 are constants.

FIGURE 2. The Degn-Olsen-Perram model. A is $[O_2]$, B is [NADH], and X and Y are the concentrations of two reaction intermediates.

the trajectory of a dynamical system is a phase portrait, in which two (or possibly more) dependent variables are plotted against each other. The plane (or higher dimensional space) in which a phase portrait is drawn is the system's phase space. Figure 4 schematically shows the relationship between time series and phase portraits for simple and complex oscillations. In either case, the trajectories in such a system trace out a closed curve. Note that Figure 4b is actually a simple (non-self-intersecting) closed curve in a three, or higher, dimensional phase space. A trajectory can never actually intersect itself in phase space (Arnol'd, 1973). Phase portraits are very useful for focusing on the qualitative behavior of a dynamical system.

The transition from stable steady states to chaos generally does not occur gradually but rather is punctuated by sudden, qualitative changes in behavior. A sudden change in either a mathematical model or a physical system is called a bifurcation (Guckenheimer and Holmes, 1983). One way to study a system's bifurcation behavior is to first set all of its parameters (in this case, the rate constants) so that the system is in a stable steady state and then to vary one of the parameters (now called the bifurcation parameter) while observing how the system's phase portrait changes as a function of the bifurcation parameter. Figure 5 schematically represents the changes in a system's phase portrait as the system undergoes two important kinds of bifurcations: the Hopf and the torus bifurcations.

A Hopf bifurcation occurs when a system's qualitative behavior changes from a stable steady state to simple oscillations (a supercritical Hopf bifurcation; Segal, 1980). A system's phase portrait signals a Hopf bifurcation by changing from a

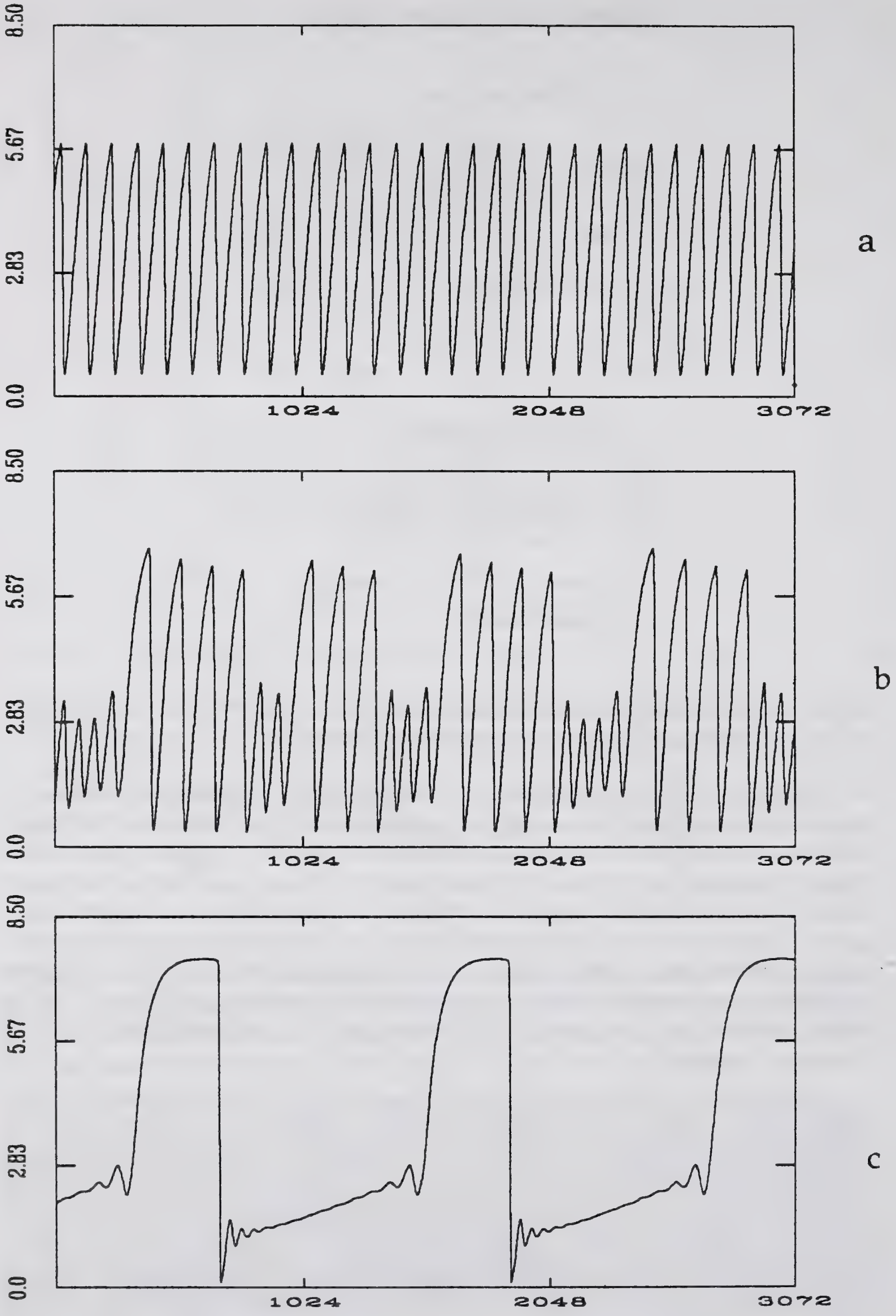

FIGURE 3. Calculated time series in A ($[O_2]$) from the DOP model. The shape of the oscillations was controlled by the value of the rate constant k_1. The values of k_1 were: a) 0.12; b) 0.9; and c) 0.048. The values of the other rate constants were: $k_2 = 1250$, $k_3 = 0.046875$, $k_4 = 20$, $k_5 = 1.104$, $k_6 = 0.001$, $k_7 = 0.89$, $k_{-7} = 0.1175$, and $k_8 = 0.5$. The time units are arbitrary.

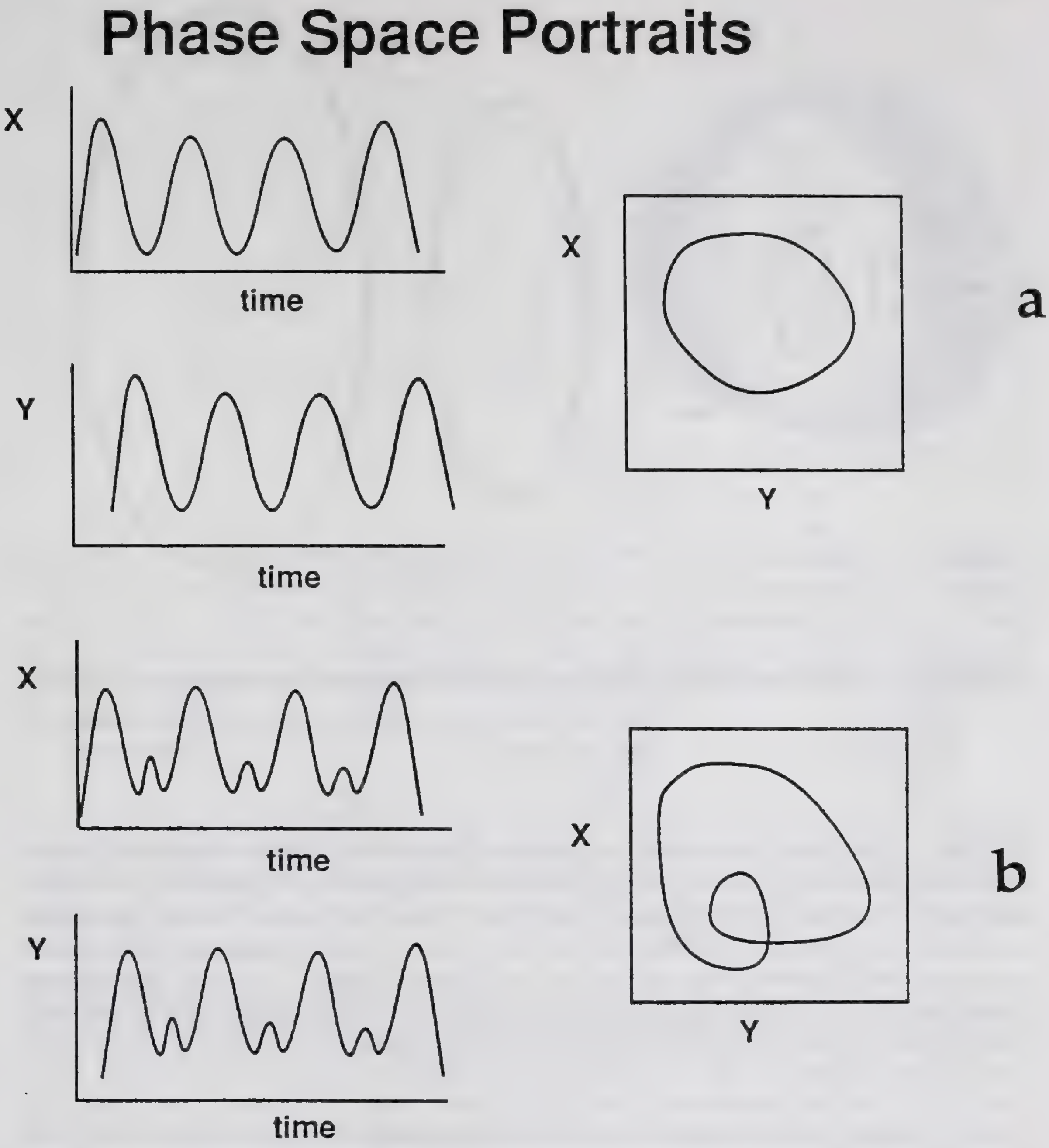

FIGURE 4. Schematic time series and phase portraits for simple and complex osciallations.

point to a simple closed curve called a limit cycle. The limit cycle grows as the the bifurcation parameter moves further from the Hopf bifurcation point, and its location in phase space may change as well. If a system has at least three degrees of freedom, it can undergo another bifurcation which gives rise to the three dimensional analog of a limit cycle: a torus (which is simply the surface of a doughnut). A torus bifurcation can be thought of as a second Hopf bifurcation and is technically known as a Naimark-Sacker bifurcation (Langford, 1983). Figure 6 shows a limit cycle and a torus actually calculated from the DOP model. The bifurcation parameter in Figure 6 is k_7. Notice that the trajectory covers only the surface of the torus and does not intrude into the interior.

As demonstrated in Figure 7a, a torus can be cut and folded into a flat sheet (Abraham and Shaw, 1984). Under some conditions, a trajectory can wind around

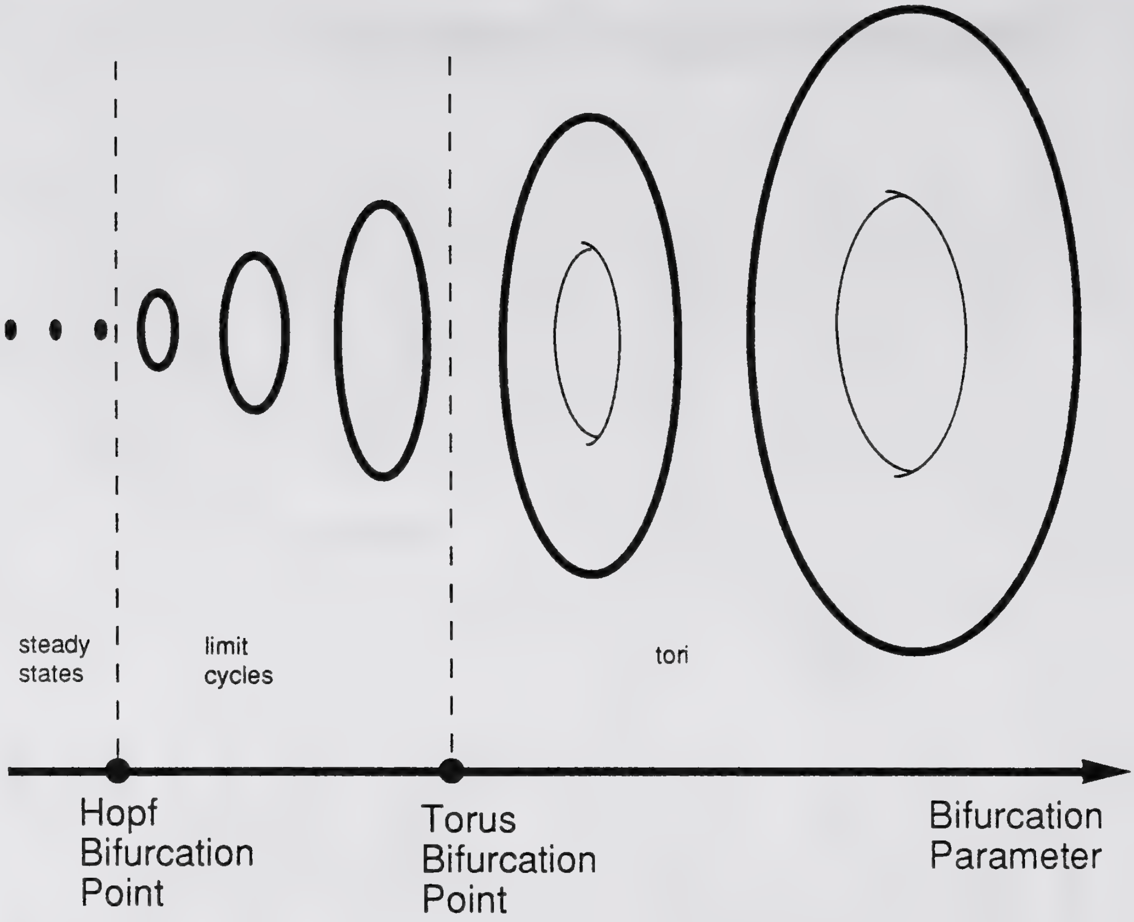

FIGURE 5. Schematic bifurcation diagram. The system starts (at the left) at a stable steady state. As the bifurcation parameter is tuned, the steady state moves, and then the system undergoes a Hopf bifurcation. As the bifurcation parameter is tuned past the Hopf bifurcation point, a limit cycle grows out of the (now unstable) steady state. The oscillations continue to grow, and then the system undergoes a second Hopf bifurcation, a torus bifurcation. Past the torus bifurcation quasiperiodic (see text) oscillations grow out of the (now unstable) limit cycle.

a torus forever without ever exactly retracing itself, and in the limit of infinite time, it will then densely cover the torus (or flat sheet). When a system densely covers the torus, it is called quasiperiodic (Figure 7b). Under other conditions, after one (or more) trips around the torus, a trajectory may begin to exactly retrace itself, so that it will *not* densely cover the torus. This latter behavior is called frequency locking (Figure 7c). The complex oscillations that have been observed in the DOP model (as well as other models of the PO reaction and other chemical oscillators) are examples of frequency locking; however, the quasiperiodic states that densely cover the torus have not been reported until now (nor had the torus bifurcation itself been identified in any model of the PO reaction). A quasiperiodic state and a nearby frequency locked state are shown in Figure 8 (Figure 6b is also an example of quasiperiodicity). These diagrams show clearly that the frequency locked state is a trajectory on the surface of a torus.

COMPLEX OSCILLATIONS AND CHAOS

Simple frequency locking does not account for many of the complex oscillations that we have found in the DOP model. Figure 10 shows two complex oscillations

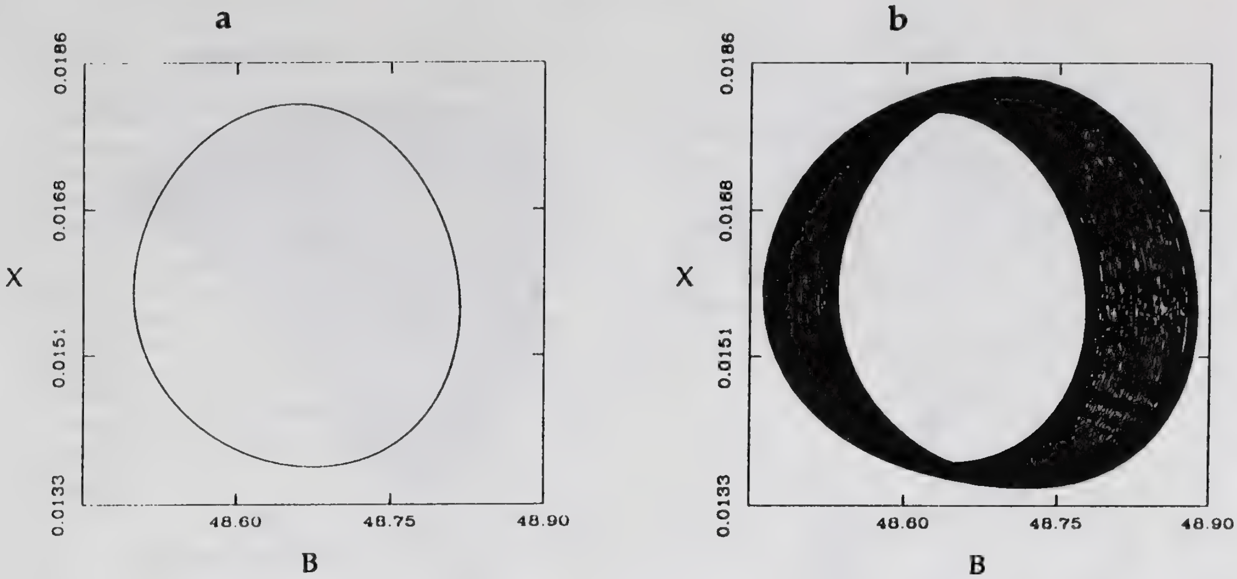

FIGURE 6. Phase portraits from the DOP model showing a limit cycle (6a) and a torus (6b). All rate constants except k_1 and k_7 are as in Figure 3, and in both 6a and 6b, $k_1 = 0.0761555$. The limit cycle in 6a was obtained with $k_7 = 0.2$. The torus in 6b was obtained with $k_7 = 0.15$. Notice how tightly wound the trajectory in 6b is (only one trip around the torus is shown). Also, the inner and outer diameters of the torus are nearly identical.

at very similar parameter values. The state in Figure 10a is 4^{10}, while that in 10b is ($4^9\,4^{11}$). The intriguing thing about Figure 10b is that the small oscillations appear to go through two different sized holes. To cover such a doughnut (with two holes) with a simple torus requires the mathematical impossibility that the torus should intersect itself.

A possible explanation for Figure 10b is that the system has undergone a *third* Hopf bifurcation. The result of a third Hopf bifurcation would be a three-torus (Berge, *et al.,* 1984) as opposed to a two-torus, which is what we've been looking at up to now). A three-torus is a three dimensional surface of a *four dimensional* object, so the trajectory in Figure 10b could sit on (actually *in*) a three-torus without necessitating that the torus intersect itself. A third Hopf bifurcation is possible in the DOP model, because it has four variables and therefore a four dimensional phase space (up to this point, only two dimensional projections from this four dimensional space have been discussed).

A three-torus can be unfolded to a solid parallelepiped (a higher dimensional analog to Figure 7a cannot be drawn, since this would require four dimensions). On a flat sheet (i.e., a two-torus), only quasiperiodicity or frequency locking can occur, because the trajectory must be parallel to itself every time it goes around the torus (or across the sheet), otherwise it would intersect itself, which it cannot do. In a three-torus (a solid region), however, there is much more freedom of movement and the trajectory need not remain parallel to itself in order to avoid self intersection. So a new type of behavior that is neither quasiperiodic nor frequency locked is possible on a three-torus. This new type of behavior is chaos (Berge, *et al.,* 1984).

The chaotic states found in the DOP model occur at parameter values close to where complex oscillations of the type shown in Figure 10b occur. In a previous

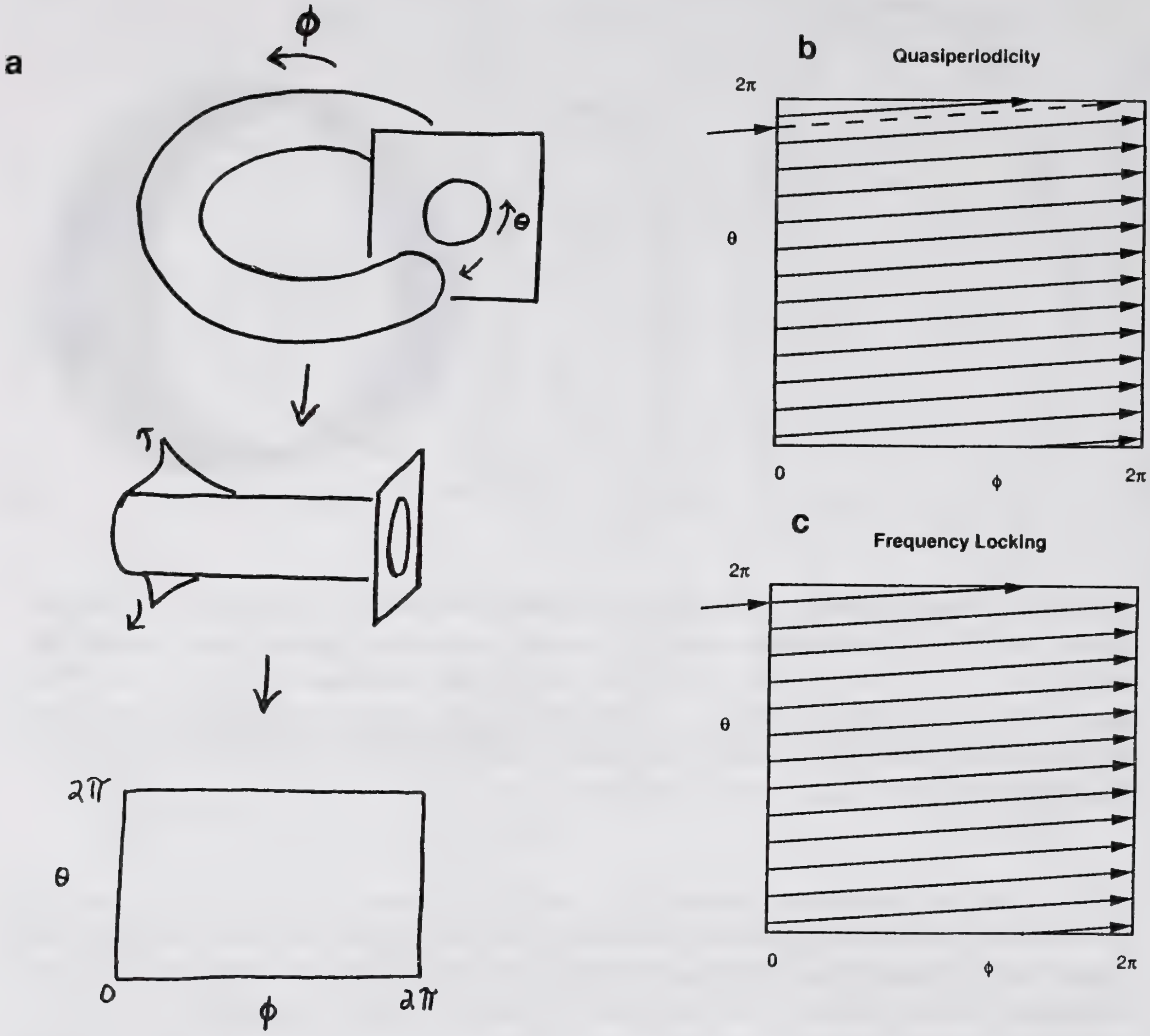

FIGURE 7. 7a shows how to turn a torus into a flat sheet. Since there are two independent angles of rotation on the torus, two edges of the sheet can be designated as axes, θ and ϕ, going from 0 to 2π. When either of the two angles reaches the value 2π, it is reset to 0, leaving the other angle unchanged. In other words, if a trajectory leaves the sheet at the top (left) it comes back on the bottom (right). 7b shows the path of a trajectory once around the torus (spread out on a sheet) in a quasiperiodic state and indicates that the trajectory will not retrace itself. Figure 7c shows a frequency locked state and indicates how it repeats itself every time it goes around the torus.

study, the complex oscillations in the DOP model were shown to form a devil's staircase structure (Larter, *et al.,* 1981). In this devil's staircase structure, parameter values at which complex oscillations of the type L^S (such as 4^{10}) occur are separated by parameter values at which combinations of the type $(L^S)_1\ (L^S)_2 \ldots (L^S)_n$, such as $(4^9\ 4^{11})$, occur. It seems that most of these combination states are periodic, that is, the combinations are regular. But chaotic states also exist, in which the combinations become random, as they do in the experimental system. A third Hopf bifurcation (the existence of which is still speculative) could explain the origin of both the regular and chaotic combinations as well as why they occur together in parameter space.

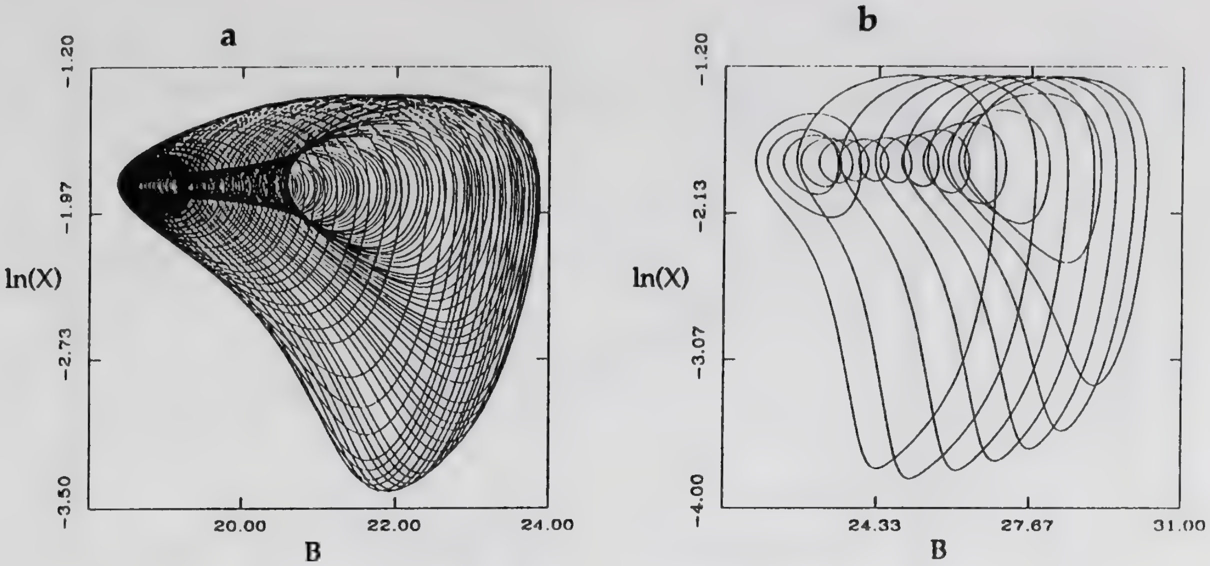

FIGURE 8. Phase portraits to illustrate frequency locking on a torus. A semilog scale is used both here and in Figure 10. All rate constants except k_1 and k_7 are as in Figure 3. In both 8a and 8b, $k_7 = 0.775$, while in 8a, $k_1 = 0.2$, and in 8b, $k_1 = 0.15$. Figure 8a is a quasiperiodic state that has already wrapped around the torus several times. Figure 8b is a frequency locked state. Notice that the torus has moved and changed shape somewhat between 8a and 8b.

CONCLUSION

The simple and complex oscillations in the DOP model arise from a Hopf and a torus bifurcation, respectively. Also, we now know (from using AUTO86) where these bifurcations occur, so that we can now predict accurately where simple and complex oscillations exist in the DOP model without doing time consuming and costly numerical simulations on a computer. Since the rate constants chosen in our bifurcation analysis correspond to experimentally manipulable parameters, this significantly enhances the predictive power of the DOP model. Additionally, quasiperiodic states have been formed, which previously were the "missing-link" in the transition from simple to complex oscillations in this model. Finally, we have shown how a third Hopf bifurcation, if it exists, could account for both the regular and chaotic combinations of complex oscillations that have been observed and that cannot be explained by simple frequency locking on a two-torus.

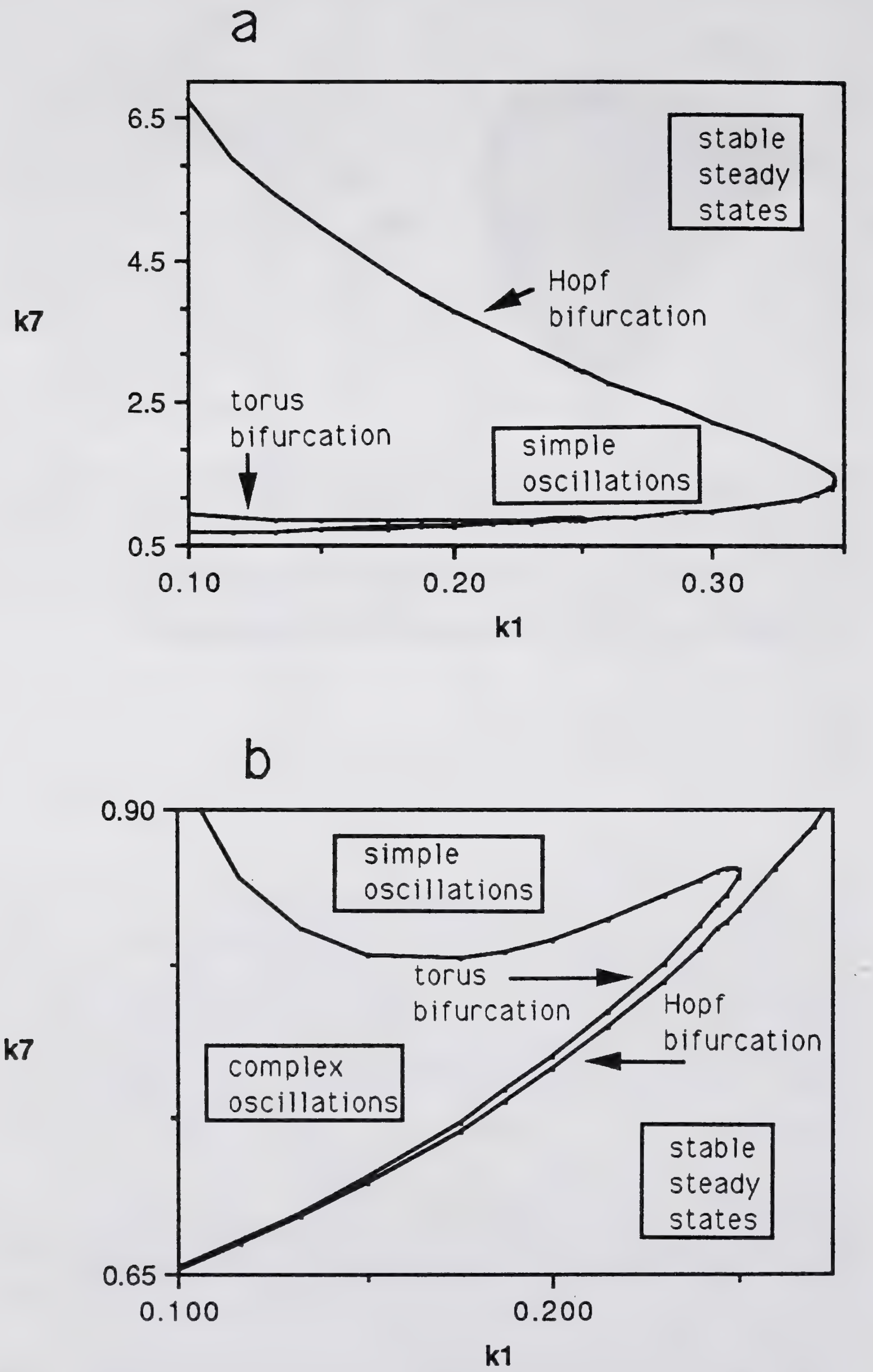

FIGURE 9. Two-parameter bifurcation diagram for the PO reaction. The two parameters are k_1 and k_7, as indicated on the axes. Figure 9b is a close-up of the part of 9a containing the torus bifurcation curve, which is barely visible in the lower left of 9a.

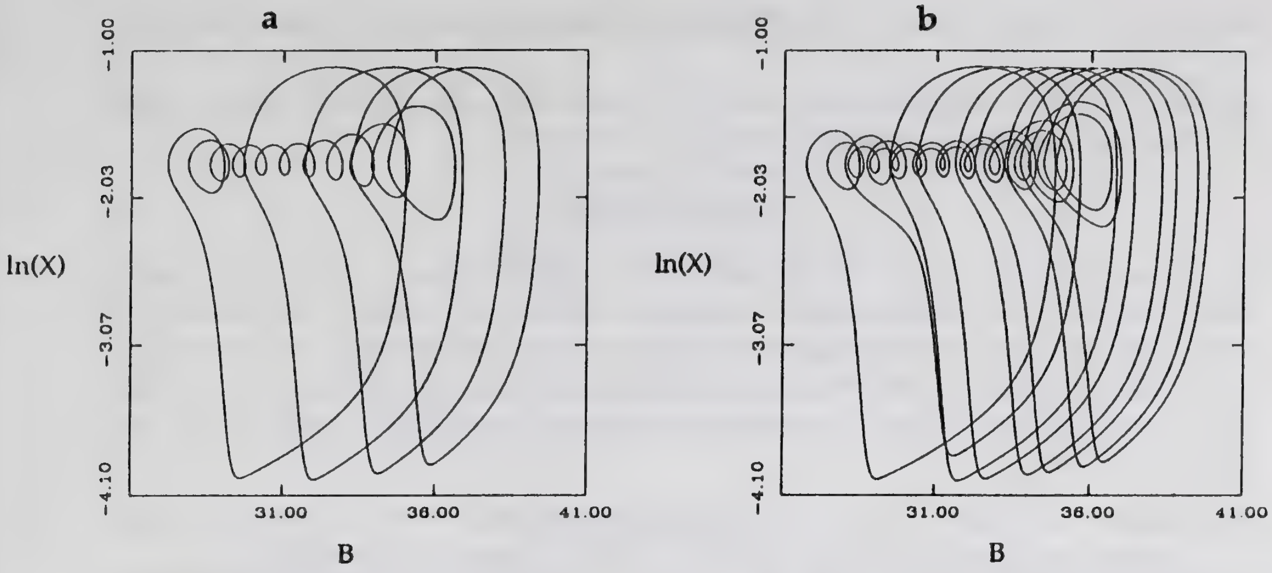

FIGURE 10. Phase portraits illustrating the two types of complex oscillations. 10a shows a 4^{10} state that can easily be explained by frequency locking on a two-torus. 10b shows a $(4^{9}\ 4^{11})$ state in which the smaller oscillations appear to trace out two differently sized holes.

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ADDENDUM

Since the time this work was submitted for publication, we have determined that the three-torus explanation suggested above as a possible mechanism by which chaos might arise in this model is not correct. Rather, the two dimensional torus goes through a "wrinkling" transition and breaks up into a fractal object which can support chaotic dynamics (Steinmetz and Larter, 1991; Larter and Steinmetz, 1991).

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ECOLOGY

Chair: Craig E. Nelson
Department of Biology
Indiana University
Bloomington, IN 47405

Chair-Elect: Paul MacMillan
Department of Biology
Hanover College
Hanover, IN 47243

ABSTRACTS

An Application of Techniques to Assess the Spatial Distribution of Land Cover or Habitat Types. Steven E. Backs, Indiana Department of Natural Resources, R.R. #2, Box 477, Mitchell, IN 47446.—Procedures to evaluate wildlife habitat often incorporate an assessment of the spatial distribution of cover types or habitat components important to a particular species. Ten "Missouri interspersion patterns" depiciting a range of forest: openland distributions were used to determine if analytical techniques to quantify spatial variables of "interspersion," "juxtaposition," and "spatial proximity" could differentiate between patterns and rank them in relative order of heterogeneity. A 3-level, systematic sampling grid was used to simulate a grid cell approach applicable to geographic information systems. Mean ranking values for spatial variables were used to order interspersion patterns by decreasing spatial heterogeneity. An index of similarity based on the coefficient of variability was used to differentiate mean values.

Seasonal Phenology of Chironomids in a Northern Indiana Stream. Martin B. Berg and Ronald A. Hellenthal, Department of Biological Sciences, University of Notre Dame, Notre Dame, IN 46556.—Although chironomids (Diptera: Chironomidae) are often the numerically dominant insects in streams, they are commonly ignored in aquatic insect life history studies. Since chironomids represent a species rich group in many stream habitats, seasonal phenologies provide insight into how members of this diverse assemblage coexist in a given stream reach. Fifteen 56.25 cm^2 Ekman grab samples were collected biweekly for one year in Juday Creek, a third-order northern Indiana stream, to examine seasonal phenologies. Forty-two co-occurring species of chironomids dominated by *Diamesa nivoriunda, Pagastia, Cricotopus bicinctus, Eukiefferiella* sp. *(claripennis* group), *Eukiefferiella* sp. *(devonica* group), *Parametriocnemus lundbecki,* and *Tvetenia* sp. *(bavarica* group) were collected. Many taxa showed temporally coordinated life cycles ranging from univoltine to asynchronous.

Breeding Status of the Loggerhead Shrike in Indiana. Kenneth M. Burton and Donald R. Whitehead, Department of Biology, Indiana University, Bloomington, IN 47405, and Chris Iverson, Indiana Department of Natural Resources, Division of Fish and Wildlife, 3900 Soldiers Home Road, West Lafayette, IN 47906.—The loggerhead shrike (*Lanius ludovicianus*) has experienced a serious decline throughout the northeastern portion of its range in recent decades. The reasons for this decline are unclear, but habitat alteration is probably the main factor. Incidental records from Indiana suggest a similar decline, and the species is now classed as endangered here. A study sponsored by the Department of Natural Resources' Nongame and Endangered Wildlife Program was begun this year to determine the shrike's status and distribution in the State, assess reproductive success, and analyze nest-site and territory characteristics. Results so far indicate that the breeding population is larger than was believed and concentrated in the southwestern portion of the State. The highest numbers of birds were found in Daviess, Dubois, Spencer, and Pike Counties. Thirty nests were monitored; 60% were successful.

The Effects of Oxygen Concentration on Embryonic Development, Post-hatching Characteristics and Sex Ratio in the Red-eared Turtle, *Pseudemys scripta*. Cory R. Etchberger, John B. Phillips, Michael A. Ewert, Henry Prange, and Craig E. Nelson, Department of Biology, Indiana University, Bloomington, IN 47405.—This study examined the effects of oxygen concentration during embryonic development in *Pseudemys scripta*. The characteristics studied included: 1) the number of days to pipping; 2) the number of days following hatching to yolk absorption (umbilical scar formation); 3) the ratio of egg mass converted into hatchling mass; 4) the amount of yolk assimilated by the hatchling; and 5) the determinaton of sex. Sex in this species is determined by temperature. Above the pivotal temperature (estimated from previous studies to be 29 C) predominantly females are produced (>30 C produces all females), while at incubation temperatures >29 C males predominate (>27 C produces all males). One hundred eggs were equally divided among four oxygen treatments: High (30% 0_2); Atmospheric (21%); Low (15%); and Low-Low (11%). All eggs were incubated at 29 C in small incubation containers enclosed in environmental chambers where oxygen concentration, temperature, and humidity were controlled: Eggs incubated in the Low-Low treatment pipped significantly later and absorbed their yolk slower than those in the other three treatments. Oxygen concentration did not affect hatchling size. In addition, when a clutch effect was accounted for, the Low-Low group converted significantly less of the egg into hatchling. Determination of sex as a function of oxygen concentration will be discussed.

Thirty-four Years of Tree Growth Data at the Southern Indiana Purdue Agricultural Center. Burnell C. Fischer and Richard K. Myers, Department of Forestry and Natural Resources, Purdue University, West Lafayette, IN 47907.—In 1953, 69 - $^{1}/_{5}$ acre continuous forest inventory (CFI) plots were established at the Southern Indiana Purdue Agricultural Center (SIPAC). The 69 CFI plots were remeasured in 1956, 1962, 1966, 1980, and 1987. Despite some timber stand improvement activities, including timber harvesting, stocking continues to increase. The initial per acre stocking in trees 9.0″ DBH and greater of 35.3 trees, 36.8 square feet of basal area, and 1197 board feet (Doyle) has increased to 63.8 trees, 73.6 square feet, and 3643 board feet. Average annual growth (net growth and ingrowth) has increased from 56 board feet/acre in the first measurement period to 145 in the 1980-87 measurement period. Increased stocking and increased numbers of trees entering the sawtimber classes over time has resulted in a decreased average DBH growth increment in the most recent measurement period. DBH growth trends follow those for other southern Indiana CFI data bases with yellow-poplar and the red oaks greatest and hickories the slowest. Pictorial changes in stand structure will be presented.

Quantitative Analysis of Four Nature Preserves in Indianapolis, Indiana. Ronald P. Hellmich, Ball State University, Indiana Department of Natural Resources, 605B State Office Building, Indianapolis, IN 46204, and Arthur L. Spingarn, Indiana Department of Natural Resources, 605B State Office Building, Indianapolis, IN 46204.—Four wooded tracts ranging in size from 8 to 18 hectares in Indianapolis were dedicated in the summer of 1987 as Indiana State Nature Preserves. A quadrat sampling method was used to tally trees from approximately 20 regularly spaced 100 m^2 plots at Woollen's Gardens, Marott Park, Spring Pond, and Eagles Crest. *Acer saccharum* was dominant among sapling (2.5 to 10 cm dbh) and trees (>10 cm dbh) and was first or second among canopy tress (>30 cm dbh). The second dominant tree species (>10 cm dbh) was different at three out of four sites, being *Fagus grandifolia* at two, and *Liriodendron tulipifera* and *Platanus occidentalis* at the remaining sites. Tree density at the four sites ranged from 339 to 500 trees (>10 cm dbh) per hectare while the mean tree diameter ranged from 14 cm at Marott Park to almost 19 cm at Eagles Crest. Quantitative sampling at Woollen's Gardens and Marott Park led to substantially different characterizations of the vegetation than previous subjective descriptions. Eagle Crest Woods was considered the best example of the classic beech-maple forest among the four. Differences in topography, water regime, visitor use, and disturbance history help explain the individualistic nature of the plant communities at these four preserves.

Summer Drought Response of an Old-Growth Woods. ELLEN M. JACQUART, Holcomb Research Institute, Butler University, 4600 Sunset Avenue, Indianapolis, IN 46208 and Arthur L. Spingarn, Indiana Department of Natural Resources, 605B State Office Building, Indianapolis, IN 46204.—Moisture stress was monitored in two canopy and two understory tree species at Hemmer Woods Nature Preserve during the 1987 and 1988 growing seasons. Measurements were taken on white oak *(Quercus alba)* and flowering dogwood *(Cornus florida)* on upland soils, and yellow poplar *(Liriodendron tulipifera)* and pawpaw *(Asimina triloba)* on bottomland soils. Radial expansion in oaks and poplars was measured using aluminum band dendrometers. Growth from June-August, 1988 was greatly reduced compared to the same period in 1987. Average pre-dawn xylem water potentials in flowering dogwood dropped to minus 20 bars in September, 1987. In June, 1988, the potentials fell to minus 14 bars, compared to minus 2 bars in June, 1987. Less extreme stress levels were observed in pawpaws. The physiological responses were closely linked to the late summer drought in 1987 and early summer drought in 1988.

Presettlement and Modern Vegetation Patterns in Wabash County, IN. DOUGLAS C. KELLER and DAVID J. HICKS, Biology Department, Manchester College, North Manchester, IN 46962.—The presettlement vegetation of Wabash County was established by study of early land survey records. The dominant vegetation types were oak-hickory, beech-maple, and floodplain forest. Oak-hickory forest tended to be associated with the better drained soils in the northwestern part of the county. Small areas of barrens, bog, and wetland also occurred. Modern forest vegetation consists of over 1200 individual patches of forest, most of them less than 5 ha.

Yellow Perch Fecundity in Indiana Waters of Lake Michigan, 1985-86. THOMAS S. MCCOMISH, Department of Biology, Ball State University, Muncie, IN 47306 and STEVEN M. SHROYER, Department of Fisheries and Wildlife, University of Minnesota, St. Paul, MN 55108.—Fecundity of yellow perch *(Perca flavescens)* was evaluated for fish from Lake Michigan near Michigan City, Indiana, in 1985 and 1986. Fish ($n = 83$) used for fecundity models ranged from 172-290 mm and age 3-6. Fecundity was estimated using both volumetric and gravimetric methods. Comparison of estimated fecundities to total egg counts revealed volumetric estimates more closely approximated the actual (mean error −3.4%, SD 8.2%) than gravimetric estimates (mean error +8.8%, SD 6.5%). Equations describing fecundity (F) as a function of total length (L) were developed as least squares regression models. Models utilized means for fish in 10 mm intervals transformed to base 10 logarithms. The 1985 and 1986 data were combined since no difference in models was found between years ($P > 0.05$). The 1985-86 model based on volumetric estimates was $\log F = -4.0396 + (3.5834) \log L$ ($r = 0.982$) while the 1985-86 model based on gravimetric estimates was $\log F = -3.8258 + (3.5097) \log L$ ($r = 0.986$). The volumetric model was used to predict fecundity based on length and age and to compare to yellow perch fecundity models from other Lake Michigan locations.

Chemically Mediated Discrimination Against Blue-green Algae by Suspension-feeding Copepods. FELIX MOXTER and WILLIAM R. DEMOTT, Department of Biological Sciences, Indiana-Purdue University, Fort Wayne, IN 46805.—Toxicity, low food value, and/or unmanageable size often make blue-green algae poor food for zooplankton. We used dual label radiotracer experiments to examine selection between high quality *Chlamydomonas* and a variety of blue-green algae by zooplankton. In contrast with nonselective *Daphnia*, the copepod *Diaptomus birgei* exhibited three patterns of selectivity: 1) several taxa, including *Aphanizomenon*, toxic *Microcystis*, and toxic *Anabaena* were ingested at low rates under all conditions; 2) *Chroococcus*, nontoxic *Anabaena*, and nontoxic *Microcystis* were strongly rejected only when high quality *Chlamydomonas* was abundant; and 3) *Glaucocystis* was ingested at high rates under all conditions. These results are in good agreement with the predictions of an optimal diet model.

Survey of Distribution of Freshwater Snails in the St. Joseph and Kankakee River Basins (St. Joseph and Marshall Counties, Indiana). T. MARK OLSEN, DAVID M. LODGE, GARY W. KOHLHEPP, and LOUISE M. WEBER, Department of Biological Sciences, University of Notre Dame, Notre Dame, IN 46556.—We determined the distribution of state-threatened and other freshwater snail species in two drainage basins (St. Joseph and Kankakee) in two northern Indiana counties (St. Joseph and Marshall). In each basin, 36 sites were randomly chosen: 18 were lentic and the remainder were either streams or ditches. Depending on substrate present, each site was sampled with a kick net and/or quadrat. ANOVA was performed to test differences in species abundance among habitats and basins. Twenty-two species of snails, including three threatened species *(Campeloma decisa, Goniobasis livescens, Lymnaea stagnalis)* were found. *Pleurocera acuta* and *P. canaliculatum* were most abundant ($p < 0.05$) in ditches and *Gyraulus parvus* was most abundant ($p < 0.05$) in lentic habitats. *Valvata lewisi* was more abundant ($p < 0.05$) in the Kankakee river basin. Habitat appeared to be more important than biogeographic history in determining snail distribution.

Does the Female Northern Cricket Frog *(Acris crepitans)* Discriminate Male Advertisement Calls Based on Frequency (Pitch) Differences? STEPHEN A. PERRILL, Department of Biology, Butler University, Indianapolis, IN 46208.—Two choice discrimination experiments were conducted on female cricket frogs that had recently been removed from amplexus. Speakers for broadcasting the male advertisement call were placed 2 m apart and the female was released at the center position, 1 m from each speaker. Sound intensity was equalized at the center release spot with a Bruel and Kjaer integrating sound level meter (model 2230) before each trial. Two experiments were conducted: 1) a note from a natural call from a population in east Texas with a dominant frequency of 3800 Hz was dubbed on one track of a tape and paired with a note from a natural call from a population in central Indiana with a dominant frequency of 3500 Hz on the other tape track; and 2) a synthetic call with a dominant frequency of 3500 Hz was paired against a synthetic call with a dominant frequency of 3800 Hz. These two tests were performed on 14 frogs at a sound pressure level of 75 dB. Fifteen frogs were given the same tests at a sound pressure level of 89 dB. The female frogs discriminated between some of the choices but results remain unclear for others.

The Effects of Temperature on Sex Development in the Iguanid Lizard *Sceloporus undulatus*. BRIAN E. VIETS, Department of Biology, Indiana University, Bloomington, IN 47405.—Sex-determining patterns in lizards are poorly understood. Presently, only five of some 3300 species have been examined. Two lizards are known to have genetic sex determination (GSD), and three are known to have temperature-dependent sex determination (TSD). Due to the small number of lizards investigated thus far, a survey of additional species may be useful before any adaptive benefits of either sex-determining pattern can be determined. *Sceloporus undulatus* was examined for its sex-determining pattern as part of larger study on the sex-determining patterns of lizards. Although *S. undulatus* lacks heteromorphic sex chromosomes, its sex was found to be determined genetically. This species represents a third documented case of GSD in lizards. Eggs were incubated at 24°, 25°, 27°, 28°, 30°, 32°, and 34° C. The sex ratio at each temperature was not significantly different from 1:1. Days to hatching was inversely proportional to incubation temperature, and was significantly different at each temperature. The effects of temperature, sex, and clutch on hatchling size also were examined. Abnormalities occurred in 44% of the hatchlings. Defects were independent of temperature, but clutch specific.

The Role of Perceptual Biases in Food Selection by Suspension-feeding Copepods. M. DESIREE WATSON and WILLIAM R. DEMOTT, Department of Biological Sciences, Indiana-Purdue University, Fort Wayne, IN 46805.—We used radiotracer experiments to test the effects of algal size, motility, and extracts on food selection by planktonic copepods. Several co-occurring copepod species exhibited similar preferences for larger high quality algae over smaller high quality algae. *Tropocyclops prasins* exhibited a strong preference for motile flagellates, whereas *Diaptomus birgei* did not discriminate between motile and nonmotile forms. The addition of algal extracts did not influence patterns of selectivity or feeding rates. Preferences for large or motile cells are probably due to differential detection rather than decision-based selection. The results of experiments with algal exudates suggest that copepods detect algae by mechanoreception rather than distance chemoreception.

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COMPOSITION AND HEIGHT GROWTH OF NATURAL REGENERATION IN A MESIC, OAK-DOMINATED FOREST FOLLOWING A SHELTERWOOD HARVEST

William D. Lambert and George R. Parker
Department of Forestry and Natural Resources
Purdue University
West Lafayette, Indiana 47907

INTRODUCTION

A characteristic of many Indiana forest stands located on mesic sites is a well-developed, even-aged canopy dominated by oak species (white oak, *Quercus alba,* in particular). The natural development of regeneration beneath these oak stands includes very little white oak; certainly not enough to maintain white oak as a major component in the future stand (Merritt, 1979). In fact, a subcanopy of relatively shade tolerant species may develop and effectively prevent newly established oak seedlings or sprouts from gaining dominance or co-dominance after disturbance or removal of the main canopy (McGee, 1986). Efforts to naturally regenerate oak have been focused on drier sites with little subcanopy development, where competition for light may not be as severe as on more mesic sites (Sander, *et al.,* 1983).

The literature suggests that a shelterwood system may be employed to promote acorn production, germination, establishment, and growth of white oak seedlings. Sander (1977) states that an adequate number of white oak seedlings or sprouts 4.5 feet tall or taller at the time of overstory removal will provide rapid growing white oak sprouts that will be able to compete with other quick growing species. Sander also cautions that overstory removal with no treatment to the subcanopy may result in vigorous resprouting of the subcanopy trees which may overtop the white oak seedlings. The objective of this paper is to examine the effects of subcanopy removal treatments on the growth of white oak seedlings and sprouts as well as other species over the 1988 growing season.

METHODS

The study area is a thirty acre forest stand at Miller-Purdue Agricultural Center, located in eastern Grant County, Indiana, approximately two miles east of Upland. This site is located in the Bluffton Till Plain Section of the Central Till Plain Natural Region as described by Homoya, *et al.* (1985). The soil association at this site is the Glynwood-Pewamo-Morley Association, characterized by nearly level, deep, moderately well to poorly drained, moderately fine textured soils formed in glacial till. The two soil types found at the study site are Blount silt loam, which is somewhat poorly drained, and Morley silt loam, which is well drained.

The overstory is composed primarily of white oak and northern red oak (*Q. rubra*). The subcanopy is composed of sugar maple (*Acer saccharum*), American elm (*Ulmus americana*), red elm (*U. rubra*), white ash (*Fraxinus americana*), black cherry (*Prunus serotina*), American basswood (*Tilia americana*), bitternut hickory (*Carya cordiformis*), and shagbark hickory (*C. ovata*).

A February 1987 shelterwood harvest in the southern one-third of the stand removed approximately forty percent of the overstory. Forty-eight 20 m x 30 m plots were located in the shelterwood area, and fifteen of the interior plots were selected for this study. Either the west half or the east half of each plot was randomly assigned to examine natural regeneration, and the other half was used for a planting study. Each natural regeneration half-plot (referred to hereafter as experimental unit) was randomly assigned one of the following three treatments: 1) control (the subcanopy was left intact); 2) subcanopy removal (all trees taller than 4.5 feet were cut off at the base or girdled); and 3) subcanopy removal plus herbicide (the same treatment as in number 2 above with an 18% glyphosate solution applied to the cut stumps or to the girdle cuts).

In each experimental unit, twelve plot centers were systematically located five meters apart, two and one-half meters from each edge. The plot center marked the center of each of the twelve 5 m x 5 m plots in each experimental unit. In total, there are 180 5 m x 5 m plots with 60 in each treatment. The nearest seedling or sprout to the plot center less than 4.5 feet tall of each tree species was tagged after the subcanopy removal treatments, and the height and current season's growth measured. The number of current season's flushes, and the total number of flushes were counted for each individual.

RESULTS AND DISCUSSION

The occurrence of each species throughout the 180 5 m x 5 m plots is reported in Table 1. Eight other tree species were recorded, but the frequency of occurrence of each of these was less than six plots each. Only the ten most frequently occurring species were used in the following statistical analysis. White oak is the second most frequently occurring species, but of the ten species, white oak is the shortest (Figure 1) as well as the slowest growing species (Figure 2).

The mean current season's growth for each species by treatment in Figure 2 shows varying responses to the removal treatments. Curiously, the growth of white oak seedlings and sprouts is significantly greater ($P > .05$, SNK Mean

TABLE 1. Frequency of occurence of seedlings and sprouts of each species in a February, 1987 shelterwood harvest at Miller-Purdue Agricultural Center (1988). There are 180 total plots.

Species	Number of Plots
Sugar maple	157
White oak	137
White ash	124
Bitternut Hickory	100
Red elm	95
American elm	72
Northern red oak	61
Shagbark hickory	58
Black cherry	54
America basswood	53
Misc. species[1]	21

[1] Black walnut, bur oak, chinkapin oak, hackberry, sassafras, redbud, and white mulberry.

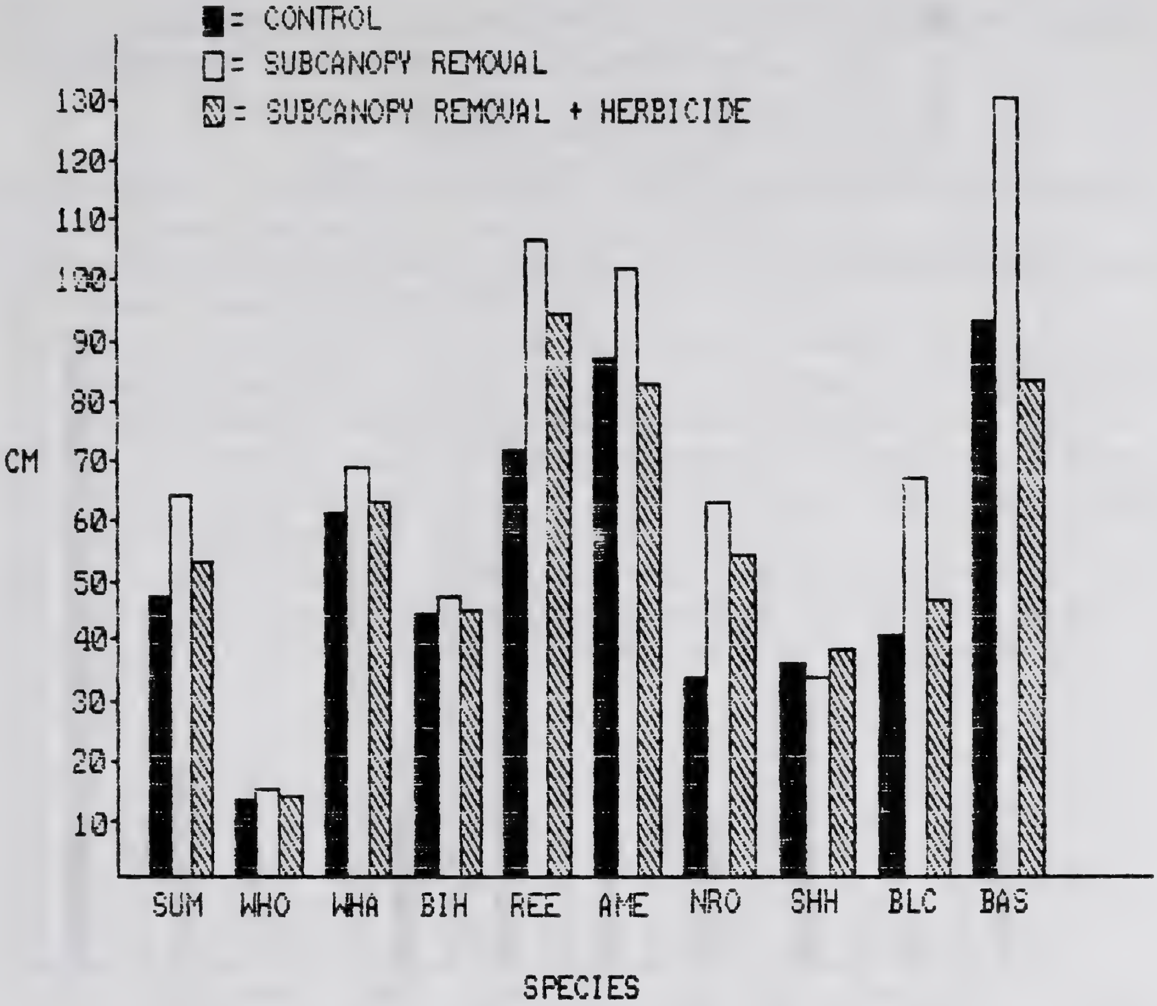

FIGURE 1. Mean total height of seedlings and sprouts for each species by treatment in February, 1987 harvest area at Miller-Purdue Agricultural Center (1988).

Separation Test) in the removal treatment than in the herbicide treatment. There was no significant difference at the 0.5 level between the control and the removal treatments. Red elm and black cherry also grew significantly more in the removal treatment than in the herbicide treatment. Sugar maple grew significantly more in the removal treatment than in the control treatment, as might be expected. American elm, red oak, and American basswood show no significant differences in growth, probably due to substantial unequal distribution between treatments.

Some of the variation in mean height growth between the treatments for each of the species is related to the proportion of true seedlings to sprouts in each treatment. Mean height growth for sprouts is significantly greater ($P <. 05$) than mean height growth of true seedlings for all species except basswood (only one true seedling was found). Sugar maple, white oak, red elm, and black cherry all have proportionately more sprouts in both removal treatments and thus greater growth. However, only sugar maple shows a significant increase in growth between the removal treatment and the control.

While the mean height growth varies by treatment for each species, it is evident that white oak seedlings have the shortest mean height and the lowest mean height growth. The remaining nine most frequently occurring species' had significantly greater mean height and mean height growth than that of white oak.

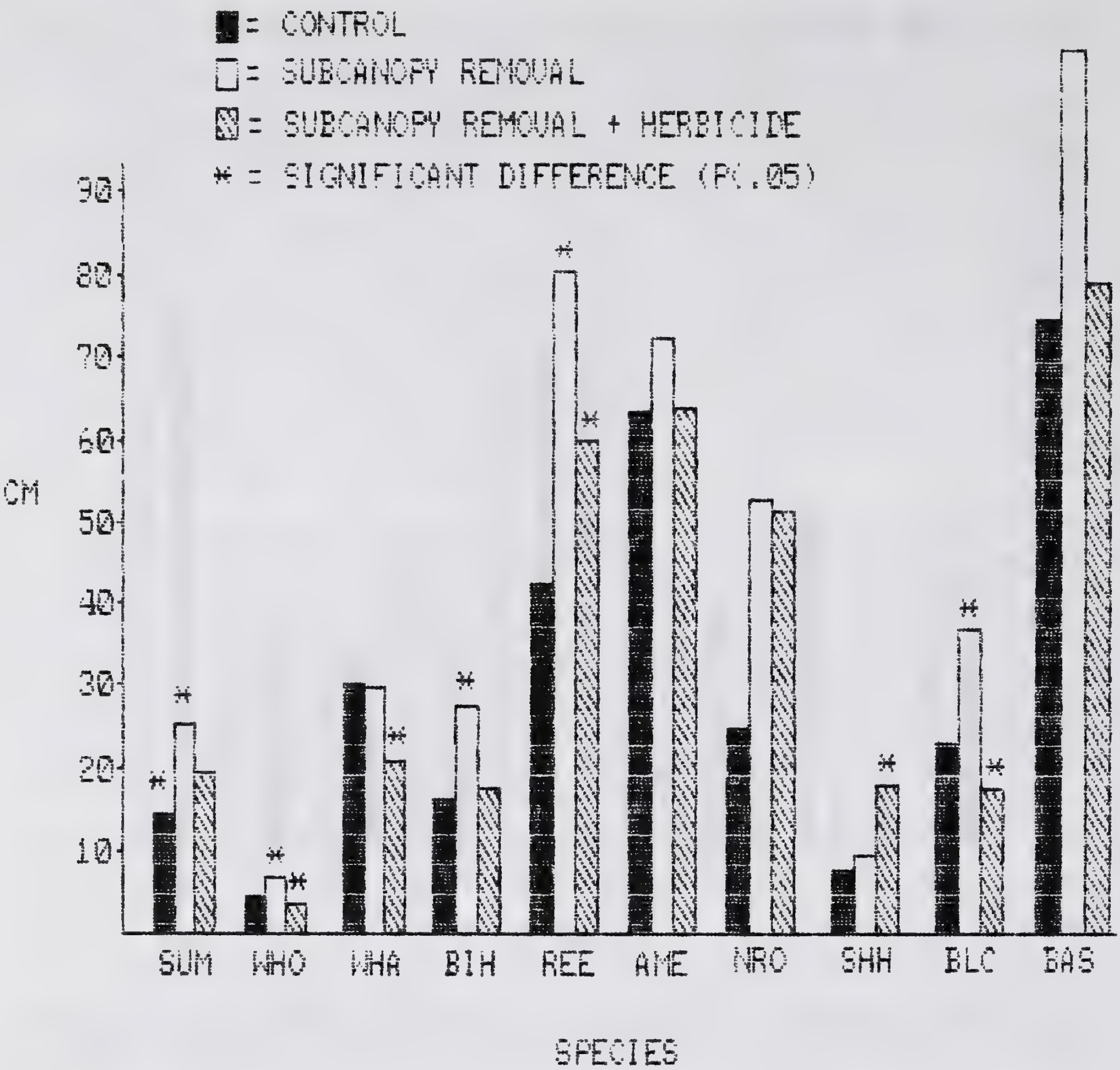

FIGURE 2. Mean height growth of seedlings and sprouts for each species by treatment in a February, 1987 shelterwood harvest area at Miller-Purdue Agricultural Center (1988).

True white oak seedlings have the youngest mean age, a little over two years (flushes). Sugar maple and white ash have the oldest mean age, just over seven years (flushes) for both species. While the sprouts of white oak may be older than the mean true seedling age, they are not as old as the other species' sprouts and do not grow as fast. No white oak saplings were found in the subcanopy in any of the experimental units, but all of the other nine species had substantial numbers of saplings and pole-sized trees removed in the subcanopy treatments. Sprouts from these cut trees are the sprouts with which white oak is competing. The herbicide treatment may have slowed the height growth for most species (Figure 2), but the mean height growth for white oak is still less than that of the other nine species.

The white oak individuals sampled are being overtopped and may never reach the 4.5 feet Sander (1977) recommends before overstory removal without additional cultural treatment to the competing understory vegetation. Removing and chemically treating the subcanopy well before the shelterwood harvest may reduce or eliminate the vigorous sprouting of the subcanopy trees. When the shelterwood harvest is completed, the white oak seedlings and sprouts will then be competing with vegetation of similar size.

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FOOD HABITS OF SALMONINE PREDATORS IN INDIANA WATERS OF LAKE MICHIGAN COMPARING THE EARLY 1970's WITH 1984-86

Thomas S. McComish
Aquatic Biology and Fisheries
Department of Biology
Ball State University
Muncie, Indiana 47306

ABSTRACT: Salmonine predator-prey relationships were investigated for extreme southern Lake Michigan waters in Indiana from April to September of 1984-86 and compared to 1970 food habit information. Trawling on index zones in Indiana waters of Lake Michigan revealed changes in relative abundance of potential forage fish eaten by salmonines, including alewife (*Alosa pseudoharengus*), yellow perch (*Perca flavescens*), bloater (*Coregonus hoyi*), and rainbow smelt (*Osmerus mordax*). In 1973, the potential forage base was dominated by alewives (47%) followed by rainbow smelt (27%) and yellow perch (26%). By comparison, in 1984-86, yellow perch dominated (84%) followed by rainbow smelt (9%), bloater (6%), and alewife (1%). Food consumed in 1970 by the major salmonine predators, including coho salmon (*Oncorhynchus kisutch*), chinook salmon (*Oncorhynchus tshawytscha*), and lake trout (*Salvelinus namaycush*), was compared to 1984-86, revealing continued importance of the alewife in the diet even though trawl catches showed its population density had declined sharply. In 1970, alewives comprised 93-100% of food comsumed and continued as the dominant forage fish eaten in 1984-86 at 44-56% of the diet. Even though yellow perch dominated the potential forage fish base in 1984-86, it accounted for only 8-30% of the food consumed, and it was not a food item in 1970. Other major forage fish consumed in 1984-86 included rainbow smelt, also eaten in 1970, and bloater, which was not a food in 1970. Steelhead (*Oncorynchus mykiss*) food habits, evaluated only in 1984-86, also revealed the alewife as the major food item at 48%. No positive size selection by salmonine predators for forage fish prey was found. Salmonines tended to feed on all sizes of forage in 1984-86, probably due to continued preference for the alewives which were at lower population densities.

INTRODUCTION

Salmonine predatory-prey relationships in extreme southern waters of Lake Michigan in Indiana were investigated from April to September during 1984-86. The purpose of this work was to compare salmonine diets for 1984-86 to those for

TABLE 1. Sample size (n) and length ranges (cm) of salmonine species sampled from Indiana waters of Lake Michigan in 1970 and the 1984-86 average.

Predator Species	**Sample Size (n) and Length Range**					
	1970			**1984-86**		
	P[a]	**E**[b]	**cm**	**P**	**E**	**cm**
Coho salmon	34	13	46-58	720	293	30- 90
Chinook salmon	29	19	25-68	408	782	30-110
Lake trout	39	32	30-76	735	747	40- 90
Steelhead				346	416	50-100

[a] P = food present.
[b] E = empty.

1970 (McComish and Miller, 1976). Insight into diet changes was obtained by comparing the food consumed by coho salmon (*Oncorhynchus kisutch*), chinook salmon (*Oncorhynchus tshawytscha*), lake trout (*Salvelinus namaycush*), steelhead trout (*Oncorynchus mykiss*) with the forage fish available as potential food.

The fish assemblage of Lake Michigan is currently a management dependent system dominated by introduced species (Stewart, *et al.*, 1981). The introduced salmonine predators are the key to maintaining the balance with both the other exotic fishes and the native fishes (Smith, 1968). Likewise, the population density of the exotic alewife (*Alosa pseudoharengus*) appears to be central to the continued success of the salmonine predators. The importance of the alewife as the dominant forage fish consumed by the salmonine predators both in Indiana waters of Lake Michigan (McComish and Miller, 1976) and elsewhere in the lake (Smith, 1968; Jude, *et al.*, 1987) has been well documented. Stocking success and high growth rate of the stocked salmonine species has been attributed to the abundant alewife forage base (Edsall, *et al.*, 1974). To emphasize the importance of alewives in the food base, Stewart, *et al.* (1981) warned that forage for salmonids in Lake Michigan is finite and excessive salmonid stocking could result in high salmonid mortality or poor growth.

The research reported here provides important additional insight to the interrelationships between the major salmonine predators and their forage base in extreme southern Lake Michigan. Continued successful management of the Lake Michigan sport fishery is dependant on understanding the dynamics of the lake system and the complex trophic interrelationships. This research documents the changing Lake Michigan predator-prey relationships by comparing data for the early 1970's to the mid-1980's.

METHODS AND MATERIALS

Forage fish densities were monitored on index trawl zones at depths ranging from about 3 to 7 m. A semi-balloon trawl was used to sample forage fish. It had a 4.9 m headrope and a 5.8 m footrope and was constructed of green Net-Set treated nylong thread woven to 38 mm stretch meshes in the body fitted with a 13 mm stretch mesh cod liner. It was towed at an average speed of about 3.5 mph. All trawling was completed at night in order to minimize trawl avoidance. A total of 24 tows, each of 10 min. duration, were completed each month during June,

TABLE 2. Trawl catch of utilized forage fish by species, total sampled (n), and composition (%) from Indiana waters of Lake Michigan in 1973 and the 1984-86 average.

Prey Species	Catch			
	1973		1984-86	
	n	%	n	%
Alewife	532	47	179	1
Yellow perch	286	26	19,489	84
Rainbow smelt	306	27	2,072	9
Bloater	1	T[a]	1,451	6

[a]T = less than 1%.

July, and August of 1973 and 1984-86. Additional details are given in McKeag (1987).

Stomach samples from salmonine predators were collected at sites in the Michigan City and Gary/Hammond, Indiana vicinities with the majority at Michigan City. Fish caught by sport fishermen were generally taken in or very near to Indiana waters of Lake Michigan. No attempt was made to determine the exact locations of fish capture due to potential error, but they represented a large number of dates and sites and were considered a representative sample for diet analysis.

Salmonine predators were made available for analysis due mainly to the cooperation and assistance of the charter boat captains and their personnel. Large numbers of fish were brought to onshore fish cleaning stations for stomach collection. Stomachs were removed intact from the fish, placed in Whirl-Paks, and preserved in 10% formalin for later analysis. In the laboratory, the stomach contents were rinsed with water into petri dishes, and the organisms they contained were removed, identified, counted, and measured.

STUDY AREA

Trawling to sample forage fishes was completed in established sample zones in Lake Michigan near Michigan City, Indiana (McKaeg, 1987). The lake bottom slopes gently toward offshore areas slowly increasing in depth and reaching a maximum of about 20-25 m at locations near the State line. The substrate is varied but consists mainly of a sand, clay, and shale mixture. Little structure exists on the bottom, but sharp crevice-like depressions oriented from near shore toward off shore are common westward from Michigan City, especially in the Kintzele Ditch area.

RESULTS AND DISCUSSION

Salmonine predators sampled. Large numbers of salmonine stomachs were collected for analysis in 1984-86 (Table 1). The numbers of stomachs examined by species were as follows: 1013 coho salmon, 1190 chinook salmon, 1482 lake trout, and 762 steelhead. On the average, 50% of all stomachs had food present.

TABLE 3. Diet composition (%) for major salmonine species from Indiana waters of Lake Michigan comparing 1970 with the 1984-86 average.

Prey Species	Diet by Species (%)[a]						
	Coho		Chinook		Lake Trout		Steelhead
	1970	1984-86	1970	1984-86	1970	1984-86	1984-86
Alewife	97	49	100	44	93	56	48
Yellow Perch		23		30		8	30
Rainbow smelt	3	23		17	6	31	21
Bloater				6		5	
Miscellaneous[b]		5		3	1		1

[a] 1970 results (McComish and Miller, 1976) compared to 1984-86 numerical average (%).
[b] Category includes: spottail shiners, trout-perch, and sculpins (*Cottus* spp.).

The number of salmonine stomachs sampled in 1970 included 47 coho salmon, 48 chinook salmon, and 71 lake trout (Table 1). No steelhead were available for diet analysis. Food was present in 61% of the total stomachs examined.

The sizes of fish sampled for stomachs in 1970 ranged from 25 to 76 cm and in 1984-86 from 30 to 110 cm (Table 1). Most fish (94%) were 50 cm or longer in total length.

Potential and utilized forage fishes. Changes in the numerical abundance of major potential forage fish species occurred between 1973 and 1984-86. Adult fish, here defined as age one or older, were separated from the total trawl catch for sample periods from June through August of each year (McKeag, 1987). The total trawl catch for the June through August period was compared, since annual sampling effort did not vary for 1973 or the 1984-86 period.

The major potential forage fish species available as a food source for larger predator fish included: alewives, yellow perch (*Perca flavescens*), rainbow smelt (*Osmerus mordax*), bloaters (*Coregonus hoyi*), trout-perch (*Percopsis omiscomaycus*), and spottail shiners (*Notropis hudsonius*). Although these six species made up the potential forage base, salmonine predators preferentially ate alewives, yellow perch, rainbow smelt, and bloaters. These four species comprised the utilized forage fish base.

Trawling on index zones revealed significant changes in the relative abundance of the utilized forage fish base between 1973 and 1984-86 (Table 2). The yellow perch population expanded very rapidly from only 286 captured in 1973 to an average per year of 19,489 in 1984-86 for nearly a 70-fold increase. By comparison, the alewife catch declined dramatically from 532 fish captured in 1973 to an average of 179 in 1984-86, representing a 66% decline. Rainbow smelt increased during the period from a 1973 low of 306 to an average of 2,072 in 1984-86 but with wide fluctations (McKeag, 1987). The trawl catch for bloater showed a major increase from only one fish in 1973 to an average of over 1,450 during 1984-86. These data reveal dramatic changes in the population densities of forage fish species utilized as food by salmonine predators between 1973 and 1984-86.

A comparison of the utilized forage fish in the trawl catch by percent composition for 1973 and 1984-86 also revealed major shifts in the dominant species

TABLE 4. Invertebrate prey frequency of occurrence (%) in stomachs of salmonine species sample from Indiana waters of Lake Michigan by 1984-86 average.

Invertebrate Prey	Frequency of Occurrence (%) by Predator Species Coho	Chinook	Lake Trout	Steelhead
Invertebrates	75	T[a]	T	47
Amphipoda	33			5
Coleoptera	31			37
Diptera	69	T	T	39
Hemiptera	14			9
Lepidoptera	28		T	30

[a]T = Less than 1%.

(Table 2). In 1973, the major forage fish catch was dominated by alewives (47%) followed by rainbow smelt (27%) and yellow perch (25%). By 1984-86, there was a dramatic shift to dominance by yellow perch (84%) followed by rainbow smelt (9%), bloaters (6%), and alewives (1%).

Diet shifts of salmonines. A comparison of forage fish consumed in 1970 (McComish and Miller, 1976) with 1984-86 revealed the continued importance of the alewife in salmonine diets (Table 3) even though it was nearly 70% less abundant in the forage base (Table 2). The 1970 diet evaluation for coho salmon revealed alewives as the single dominant forage fish (present in 97% of the stomachs analyzed). The 1984-86 diet evaluation revealed a striking change due to the altered population levels of forage fish available. However, the strong "preference" for alewives continued. During the 1984-86 period, coho salmon ate predominantly alewives (49%) followed by yellow perch (23%) and rainbow smelt (23%).

In 1970, diet studies for chinook salmon revealed that only alewives were consumed. In 1984-86, chinook salmon had a more diverse diet but ate mostly alewives (44%) followed by yellow perch (30%), rainbow smelt (17%), and bloaters (6%).

In lake trout, the dominant food item in 1970 was alewives (93%) followed by rainbow smelt (6%). In 1984-86, lake trout food habits were also more diverse, as they consumed mainly alewives (56%) followed by rainbow smelt (31%), yellow perch (8%), and bloater (5%).

These diet data reveal a continued dominance of the alewife in the 1984-86 diet of all major salmonine species (44-56%). Although yellow perch dominated the potential forage fish species available, comprising 84% of the trawl catch for the 1984-86 period, it was far less important than alewives as a salmonine food. Coho salmon, chinook salmon, and steelhead all consumed relatively high overall precentages of yellow perch in 1984-86 (23-30%), while the percentage eaten by lake trout was low (8%). Bloaters were eaten by both chinook salmon and lake trout in 1984-86, but they were not consumed by coho salmon or steelhead. These data seem to show that the chinook salmon has responded better to recent changes in the forage fish base than other salmonines.

Prey fish size selection. Correlations between the size of the prey fish consumed and the size of the predator salmonines were calculated for the 1984-86 period. No significant relationships were found due to the tendency by predators to consume all sizes of prey. Foraging theory promotes the concept that as predator fish increase in size, feeding efficiency requires larger prey. Jude, *et al.* (1987) found that salmonines collected inshore in southeastern Lake Michigan from 1973-82 showed significant postive size selection for both alewives and rainbow smelt. The lack of size selection for forage fish species in 1984-86 when compared to the 1973-82 data of Jude, *et al.* (1987) reflects a recent dramatic decline in the nearshore density of alewives. The density changes of forage species, especially alewives, has apparently made it necessary for salmonine predators to feed on all sizes of prey.

Invertebrates consumed. Invertebrate food items were consumed by some of the salmonine species (Table 4). Invertebrates were unimportant to both chinook salmon and lake trout (less than 1% consumed any invertebrates). Invertebrates were frequently consumed by coho salmon and steelhead from April through June of 1984-86, when 75-85% of the coho salmon and 85-100% of the steelhead were found to have eaten some kind of invertebrate. Insects in the order Diptera (flies) were the major invertebrate group consumed by both coho salmon and steelhead. Although a large percentage of coho salmon and steelhead consumed invertebrates through June, invertebrate occurrence was low after June, ranging from 0 to 13%. Fish comprised 6% to 53% of the diet of coho salmon and steelhead through June, but afterwards coho salmon and steelhead consumed fish exclusively. The shift away from invertebrates as prey was complete after June. Overall occurrence for invertebrates between April and September of 1984-86 was 75% for coho salmon and 47% for steelhead. Invertebrates were an early growth season food for coho salmon and steelhead, but they became relatively unimportant as summer progressed.

SUMMARY AND CONCLUSIONS

Trawling on index zones in Indiana waters of Lake Michigan revealed significant changes in the forage fish populations between 1973 and 1984-86. The major shifts taking place included a near 70-fold increase in abundance of yellow perch and a concurrent 66% decline in alewives. Bloaters experienced a population explosion between 1973 and the 1984-86 period. The other forage fish, rainbow smelt, fluctuated widely in number between 1984-86 (McKeag, 1987), a characteristic of this species in many lakes including the Great Lakes.

The percent composition of the forage base sampled by trawling and eaten by salmonine predators shifted dramatically between 1973 and 1984-86. In 1973, the forage base was dominated by alewives (47%) followed by rainbow smelt (27%) and yellow perch (26%). In 1984-86, the yellow perch population was the overwhelming dominant followed by rainbow smelt (9%), bloater (6%), and alewife (1%).

A comparison of the food consumed in 1970 by salmonine predators (McComish and Miller, 1976) with that eaten in 1984-86 revealed the continued importance of the alewife in the diet even though the population had declined sharply. In 1970, coho salmon consumed predominately alewives (97%). In 1984-86, coho salmon ate alewives (49%), yellow perch (23%), and rainbow smelt (23%). Chinook salmon ate only alewives in 1970 but had a diet consisting of alewives (44%), yellow perch (30%), rainbow smelt (17%), and bloater (6%) in 1984-86. In 1970, lake trout ate alewives (93%) and rainbow smelt (6%). By 1984-86, the lake trout diet included alewives (56%), rainbow smelt (31%), yellow perch (8%), and bloaters (5%). Although steelhead diet analysis was not completed in the early 1970's, they consumed alewives (48%), yellow perch (30%), and rainbow smelt (21%) in 1984-86.

Due to changes in the population densities of the utilized forage fish, significant changes have occurred in diets of all the salmonine predators from the early 1970's to the mid-1980s. Nevertheless, the alewife has continued to be a major dietary component even though its population has declined sharply and it is less available in relation to other forage fish.

The Lake Michigan salmonine sport fishery is very dependent on the alewife as a food source. The data collected between 1984-86 emphasize this fact even though the alewife population has declined to comparatively low levels. The dominance of yellow perch in the 1984-86 period has not resulted in a shift in the foraging behavior of the salmonine predators. Careful scientific management must be directed not only toward the salmonine populations but also toward the alewife population. Continued high survival and rapid growth rates of the salmonine species appears to be closely tied to the alewife and its dynamics in the Lake Michigan system. Future management decisions involving the salmonine sport fishery must carefully consider alewife population dynamics as a major impacting factor.

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SENSITIVITY OF UNDERSTORY PLANT SPECIES TO THE EDGE ENVIRONMENT OF ISOLATED WOODLOTS IN EAST-CENTRAL INDIANA

F. A. PURSELL and G. R. PARKER
Department of Forestry and Natural Resources
Purdue University
West Lafayette, Indiana 47907

INTRODUCTION

The forests of central Indiana have been fragmented since the late 1800's through clearing for agriculture (DenUyl, 1954) with remaining woodlands characterized by edge (forest-agriculture boundary) and interior environments. Wales (1972) defined edge as a "vegetal transition zone" between forest tracts bordered by adjacent agricultural fields. Edge environments have been shown to have higher light levels, higher ground surface temperatures, and increased evapotranspiration rates than interior environments (Geiger, 1966; Wales, 1972). Plant communities occupying edge environments have been shown to be structurally and compositionally different from those of interior environments (Bruner, 1977; Gysel, 1951; Ranney, 1978; Schmelz and Lindsey, 1970).

Studies have shown that the influence of edge in plant communities extends up to 30 meters in forests of this region (Bruner, 1977; Raney, *et al.,* 1981). Therefore, the small size of most remnant woodlots in Indiana may result in most having a large edge zone with little or no interior zone (Levenson, 1976; Sharpe, *et al.,* 1981).

Densities of individual plant species with distance from the forest-agriculture edge are examined in this paper to determine their sensitivity to the differing environments of the xeric edge and mesic interior. The effects of edge aspect on species density gradients were also examined. Total density of herbaceous and shrub species was compared for differences relative to distance from the edge interface and differences between aspects.

STUDY SITE

The Davis-Purdue Agricultural Center, located in Randolph County, Indiana (Figure 1), within the Bluffton Till Plain section of the Central Till Plain Natural Region (Homoya, *et al.,* 1985), is representative of the fragmented forest landscape of the agricultural areas of Indiana. The four woodlands on this farm, having areas of 2.3, 8.1, 13.5, and 20.6 ha, served as the study site. The largest woodland is a remnant, old-growth forest designated by the National Park Service as a National Natural Landmark (Parker, *et al.,* 1985), while the three remaining smaller woodlands are managed for timber production. These woodlands are inhabited by a complex of mesic and upland depressional wet site species with a significant component of oak and hickory species (Parker, *et al.,* 1985; Schmelz and Lindsey, 1970). Each woodland is surrounded by intensively managed agricultural fields. The forest-agricultural edge, the subject of this paper, was estab-

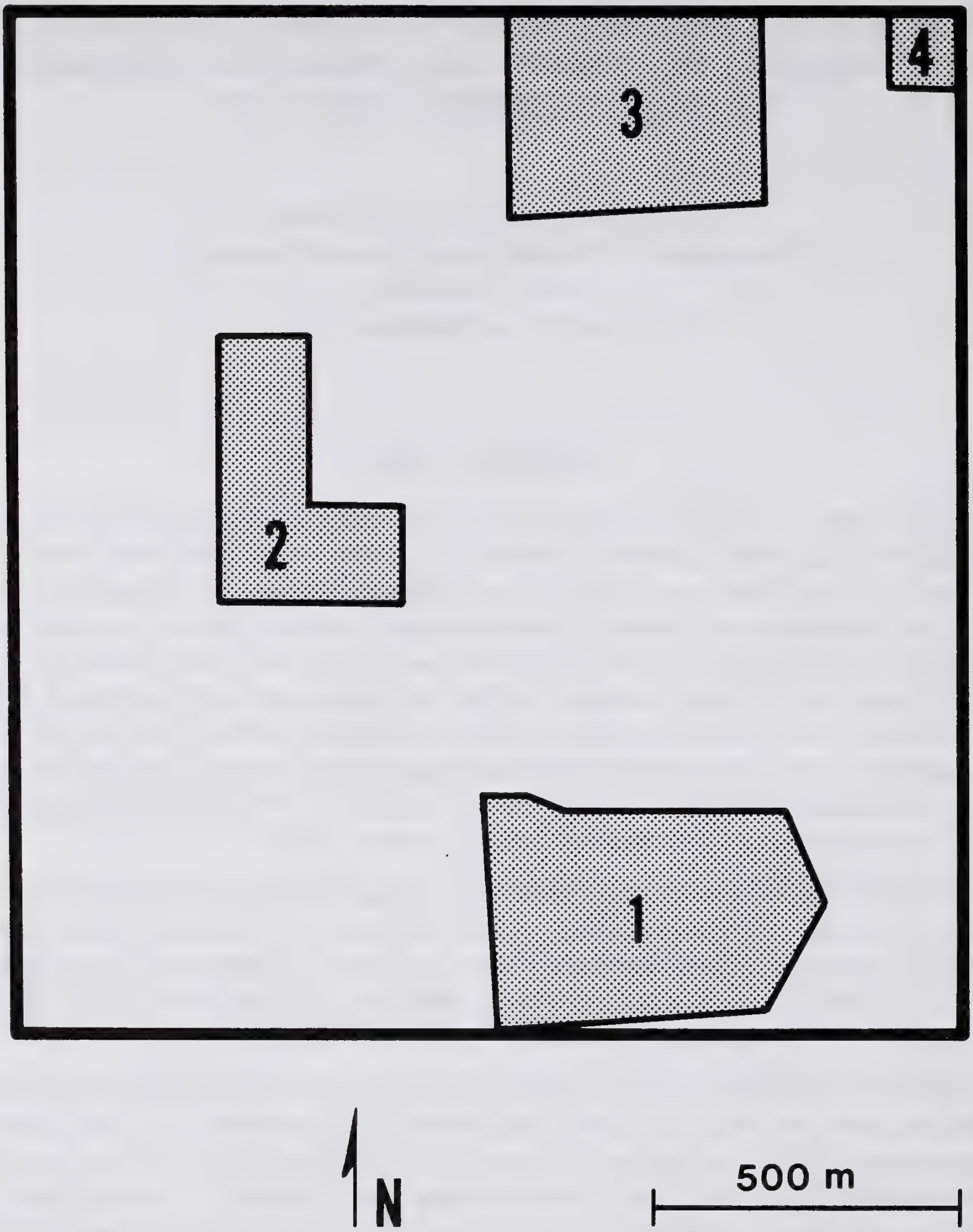

FIGURE 1. The four woodlots of the Davis-Purdue Agricultural Center are located within the same section of land and are separated by significant distances. The sizes of the woodlots are 2.3, 8.1, 13.5, and 20.6 ha.

lished prior to Purdue University acquisition in 1917 and is maintained annually by plowing or mowing.

MATERIALS AND METHODS

Forty-eight transects were established in the four woodlands; six transects in each of the north and west aspects of each woodland. These two aspects were chosen to represent the two extremes of environment in the edges of isolated woodlots with the west aspect considered the most xeric and the north the most mesic (Bruner, 1977; Raney, *et al.*, 1981). Transects were randomly placed along each aspect at least 5 meters apart and were not located within 30 meters of a parallel forest edge. Transects in all woodlands extended less than one-half the

TABLE 1. Density gradient (number individuals per plot) by aspect for selected herbaceous and woody seedling species. Different letters denote significant differences (SNK, $P < 0.5$).

		Distance from edge (meters)							
Species	**Aspect**	**0.5**	**5-10**	**10-15**	**15-20**	**20-25**	**25-30**	**30-35**	**35-40**
Cerastium	North	0.8a	2.5ab	2.1ab	2.8ab	3.3ab	2.8ab	4.1b	3.9b
spp.	West	1.5a	1.0a	1.1a	2.1a	1.8a	1.6a	2.3a	2.0a
Cornus	North	0.7a	0.5a	0.4a	0.2a	0.4a	0.1a	0.1a	0a
racemosa	West	0.5a	0.2ab	0.1ab	0.2ab	0.1ab	0b	0.1ab	0b
Cystopteris	North	0a	0.3ab	0.4ab	0.4ab	0.6ab	0.5ab	0.5ab	1.1b
fragils	West	0.1a	0a	0a	0a	0a	0.3a	0.5ab	1.0b
Menispermum	North	0.5a	0.8a	0.3a	0.4a	0.3a	0.3a	0a	0a
canadense	West	1.4a	1.2a	1.5a	0.8a	0.5a	0.6a	0.6a	0.2a
Toxicodendron	North	3.4a	2.6ab	2.7ab	2.6ab	2.2ab	1.6ab	1.3b	1.0b
radicans	West	1.3a	1.6a	1.1a	1.3a	0.6a	0.6a	0.9a	1.1a
Urtica	North	1.1a	0.7a	1.9a	2.3a	1.2a	1.0a	2.2a	2.9b
dioica	West	0a	0a	0.7ab	0.4ab	0.6ab	0.7ab	0.2ab	1.9b

distance to the opposite side of the forest, thus minimizing intrusion of edge effects from the opposing edge.

Data collection for herbs and woody seedlings began on May 15 and was completed by June 10. A line intercept sampling method was utilized by stretching a steel tape along each 40 m transect. Each transect was divided into eight, five meter plots. All herbaceous individuals touching or overhanging the steel tape were tallied by species in each plot.

Two-meter wide belt transects, subdivided into four 10 meter long plots, were used to sample shrub and tree species (the shrub strata) along the same 40 meter transects used for seedlings and herbaceous species. All woody stems greater than one meter in height and less than 10 cm dbh within one meter of either side of the transect center line were tallied by species in each plot.

All four woodlands were combined for statistical analysis. Statistical treatment of the data was by analysis of variance using SAS PROC GLM (SAS Institute, 1985). All tests were performed at the 0.05 level of significance. The Student-Newmen-Keuls (SNK) means separation test was used to examine significance of aspect and distance from edge for all species pooled and for individual species. An analysis of covariance was run to determine if species responded to canopy gaps.

RESULTS AND DISCUSSION

The total number of herbaceous and woody seedling species encountered in the sampling was just over 100. Because some species occur infrequently, the number of species tested for response to proximity to the edge was reduced to 37 for statistical analyses. The 37 species selected were chosen, because they occurred

TABLE 2. Density gradient (number of stems/ha) by aspect for selected shrub and tree species (< 10 cm dbh) with distance from the forest/cropland edge. Means with different letters denote statistical significance (SNK, $P < .05$).

		Distance from edge (meters)			
Species	**Aspect**	**0-10**	**10-20**	**20-30**	**30-40**
Celtis	North	167a	146a	125a	83b
occidentalis	West	625a	208b	125b	125b
Cornus	North	2167a	938b	708b	146b
racemosa	West	1833a	333b	146b	83b
Crataegus	North	500a	146a	83a	63a
spp.	West	521a	125b	42b	21b
Fraxinus	North	437a	271ab	167ab	104b
americana	West	625a	458a	458a	271a
Quercus	North	125a	42b	21b	21b
rubra	West	250a	63b	63b	0b

in sufficient quantities for analysis, or if infrequent, obviously exhibited a trend in density change with distance from the edge.

A significant difference in density of herb and woody seedlings was found between the north and west aspects. Within the forty meter sampling zone, the west and north edges had densities of 48.5 and 55.1 individuals per plot, respectively. Densities of the shrub strata between aspects was also significantly different, but in contrast to the herbs and seedlings, the highest density was within the west aspect with 6200 stems per ha compared to the north aspect with 5150 stem per ha. The different density response to aspect between herbs and shrubs may occur because the herbs are responding with higher densities to greater moisture levels and lower surface temperatures within the north edge. The shrubs probably respond in great density within the west edge due to higher light intensities here than would occur in the north edge. Higher shrub densities may modify the environment for herbaceous species, resulting in lowered densities for herbs on western edges.

Because of the contrast in microclimate between the west and north edge, the density distribution for individual species should show variability in response to distance from edge between aspects; that is, the edge zone will be deeper on the west side of the forest. This is indicated by density gradients for *Cystopteris fragilis, Menispermum canadense,* and *Urtica dioica* but is not clear for other species (Table 1). Shrubs responding similarly are *Crataegus* spp., *Celtis occidentalis, Fraxinus americana,* and *Quercus rubra* (Table 2). *Cornus racemosa,* while apparently an edge species, has higher densities in northern than in western edges.

When all species of herbs and woody seedlings were pooled for both aspects, the density of individuals showed no significant response with distance from the edge. However, shrub density was significantly higher within the first 10 meters

TABLE 3. Mean density (number of stems/ha) of selected shrub and tree species (< 10 cm dbh) with distance from the forest/cropland edge in woodlands at the Davis-Purdue Agricultural Center. Means with different letters denote statistical significance (SNK, $P < .05$).

	Distance from edge (meters)			
Species	**0-10**	**10-20**	**20-30**	**30-40**
Celtis occidentalis	385a	145b	145b	125b
Cornus racemosa	2000a	635b	395b	145b
Crataegus spp.	510a	105b	95b	40b
Fraxinus americana	530	315b	280b	270b
Quercus rubra	190a	40b	40b	20b
All species combined	7300a	5520b	5080b	4820b

TABLE 4. Mean density of selected herbaceous and woody seedling species with distance from the edge. Means with different letters denote statistical significance (SNK, $P < .05$) for densities of species with distance.

	Distance from edge (meters)							
Species	**0-5**	**5-10**	**10-15**	**15-20**	**20-25**	**25-30**	**30-35**	**35-40**
Certastium spp.	1.2a	1.8abc	1.6ab	2.5abc	2.6abc	2.2abc	3.2bc	2.9c
Cornus racemosa	0.6a	0.4ab	0.3b	0.3b	0.2b	0.1b	0.1b	0b
Cystopteris fragilis	0.1a	0.1a	0.2a	0.2a	0.3a	0.4a	0.5a	1.1b
Menispermum canadense	0.9a	1.0a	0.9a	0.6ab	0.4ab	0.5ab	0.3ab	0.1b
Sanicula marilandica	4.3a	6.7b	7.2b	7.0b	7.4b	6.9b	7.9b	8.2b
Toxicodendron radicans	2.4a	2.1ab	1.9ab	1.9ab	1.4ab	1.1b	1.1b	1.1b
Urtica dioica	0.1a	0.3ab	1.3ab	1.3ab	0.9ab	0.8ab	1.2ab	2.4ab
All species combined	49a	53a	51a	55a	50a	50a	52a	55a

from the edge (Table 3). This agrees with Ranney's (Ranney, *et al.*, 1981) conclusion that shrub densities decrease toward the interior. Wales (1972) also concluded that species with vigorous asexual reproduction or that are shade intolerant were more important in the edge. Species richness (species per plot) was also found to be highest in the first 10 meters from the edge, which also concurs with the findings of Ranney, *et al.* (1981).

When individual species of herbs and woody seedlings were examined, two general responses were found (Table 4): 1) species with increasing densities nearer the edge *(Menispermum canadense, Toxicodendron radicans,* and *Cornus racemosa);* and 2) species which were more dense toward the interior *(Sanicula marilandica, Urtica dioica, Cerastium* spp., and *Cystopteris fragilis).* Some species exhibited the the trend more strongly than others, but all trends were signficant.

Herb, shrub, and tree (seedlings) species were found to respond to canopy gaps due to tree falls. Herbs and tree seedlings, which had a positive response to canopy gaps, included *Aesculus glabra, Cornus racemosa, Geum vernum, Osmorhiza longistylus,* and *Solidago* spp. Shrubs and saplings showing a positive response were *Celtis occidentalis, Ostrya virginiana, Rubus occidentalis, Vitis* spp., and *Smilax* spp. These species were also typical of those found in higher densities near the edge. However, although soil temperature increases in canopy gaps similar to edges (Collins, *et al.,* 1985), canopy gaps do not represent edge conditions, since gaps lack the prevailing, below-canopy wind conditions and lower moisture levels characteristic of edges (Bruner, 1977; Collins, *et al.,* 1985; Geiger, 1966; Ranney, *et al.,* 1981). Wales (1972) considered that canopy gaps may have masked some of his data on edge gradients but concluded after investigation that the effect was minimal.

The results of this study are in accord with previous studies which found that plants react to microclimatic differences in the edge as compared to the interior of forest fragments. However, previous studies have not identified herbaceous species indicative of interior conditions. This study suggests that the distribution of some species in terms of density is responsive to an edge gradient. Generally, species showing the greatest affinities for edge zones are vines and intolerant woody species (Table 2). Two species with high fidelity for interior conditions are *Urtica dioica* and *Cystopteris fragilis*. The latter is a potential indicator species of interior conditions. Its significant increase in density within the 35-40 meter distance interval is apparent.

The depth of response by some species is also significant, since it shows edge effects to be deeper than previous studies have revealed. The data suggest that 35-40 meters is the depth of edge effects on the plant community. However, more data are needed to examine species change at distances beyond 40 meters from the edge.

ACKNOWLEDGMENTS

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ENGINEERING

Chair: Charles W. Lovell
School of Civil Engineering
Purdue University
West Lafayette, Indiana 47907

Chair Elect: David Chesak
Department of Physics
St. Joseph's College
Rensselaer, Indiana 47978

ABSTRACTS

Toward the Formation of Electrical Contacts on Single Crystal Cubic Silicon Carbide. J. J. Bellina, Jr., Saint Mary's College, Department of Chemistry and Physics, Notre Dame, Indiana 46556.——Cubic Silicon Carbide (3C SiC) has potential as a high temperature semiconducting material for advanced sensors, electrical power control in space vehicles, and future generation computers. Device quality single-crystal epitaxial films of 3C SiC have recently been grown by chemical vapor deposition on Si substrates. The technology for controlling both the bulk and the surface properties of this new material is currently in development. Research on the surface characteristics of 3C SiC will be described. The results reveal how the surface responds to heating in vacuum, in hydrogen, and in an oxidizing environment, and to ion damage, and to metal deposition.

MIDI: Musical Instrument Digital Interface. David D. Chesak, St. Joseph's College, Rensselaer, Indiana 47978.——The MIDI specifications for hardware standards and software protocols for communication between electronic musical instruments were established about five years ago by joint agreement among the major manufacturers of these products. This paper presents an interface circuit and computer programs for data exchange between a microcomputer and a music synthesizer utilizing the MIDI specifications.

Chemical and Physical Characterization of Indiana Bottom Ashes. W. H. Huang and C. W. Lovell, School of Civil Engineering, Purdue University, West Lafayette, Indiana 47907.——A byproduct of coal-fired power production in Indiana is an enormous volume of bottom ash, and the power companies spend a considerable sum in waste-disposal of it. The Federal Highway Administration and the Indiana Department of Highways are currently engaged in a study to determine potential uses of these ashes in Indiana highway construction. This usage depends upon both the chemical and physical behavior of the materials. The paper describes what has been learned to date about selected Indiana ashes.

The Sources of Indiana Coal Ash: Road Building Materials? Robert Rahn, Indiana Department of Highways, 120 South Shortridge Drive, Indianapolis, Indiana 46219 and C.W. Lovell, School of Civil Engineering, Purdue University, West Lafayette, Indiana 47907.——Enormous quantities of coal ash are produced in Indiana as waste from power generating facilities. Both the finer constituents (fly ash) and the coarser (bottom ash) have had limited usage in the construction of Indiana highways. However, there is a substantial motivation to increase such usage, particularly for the bottom ash. At least some of this material seems suitable for incorporation in highway embankments, subgrades, and subbases. One step in further investigating the suitability of these ashes has involved detailed study of the way selected power companies store their wastes. Some storage practices are found to be much more conducive to the economic retrieval and utilization of the ashes than others. The practices are illustrated by a videotape recently produced by the Indiana Department of Highways.

ENTOMOLOGY

Chair: Larry W. Bledsoe
Department of Entomology
Purdue University
West Lafayette, Indiana 47907

Chair-Elect: Claude Wade
Division of Entomology Room 613
State Office Building
Indianapolis, Indiana 46204

ABSTRACTS

A Survey of Mosquitoe Breeding Sites in Wayne County. Linden L. Duncan and Harold L. Zimmack, Department of Biology, Ball State University, Muncie, IN 47306.——Various types of mosquitoe larvae habitats, the species found at these sites, and the controls used against these sites will be presented.

Vector Competency of *Ixodes cookei* for Lyme Disease. Todd Glancey and Robert Pinger, Department of Physiology and Health Science, Ball State University, Muncie, IN 47306.——The etiologic agent of Lyme disease is the spirochete, *Borrelia burgdorferi,* which is transmitted by ticks in the genus *Ixodes. Ixodes dammini*, *I. pacificus*, and *I. ricinus* are proven vectors of Lyme disease. The capabilities of other tick species, such as *I. cookei,* in transmitting the spirochete are still uncertain. *I. cookei* was chosen to be used in a vector competency experiment because it is the most common *Ixodes* species encountered in Indiana and it has been a suspected vector in Canada. *I. dammini* was used as a control species. Larvae of each species were allowed to feed on hamsters infected with *B. burgdorferi.* Nymphs grown from these larvae were fed on uninfected hamsters fed upon by nymphs of *I. dammini* but not of the *I. cookei.*

Forensic Entomology in Indiana. Neal H. Haskell and Larry W. Bledsoe, Department of Entomology, Purdue University, West Lafayette, IN 47907.——The field of forensic entomology has had little exposure to the scientific community and even less to the general public, although symposia have been conducted at regional and national scientific meetings to introduce the complexities of this topic. The forensic entomologist is a member of the forensic science team. Other team members include: pathologists, crime scene technicians, odontologists, anthropologists, and botanists. Each member will collect the evidence necessary for their evaluation and consult with the other team members as to their conclusions. A consensus of opinion can then be reached as to the true sequence of events surrounding the case. Scentific research by the forensic entomologist is critical if the field is to continue to achieve the potential accuracy of the post-mortem interval estimations. Carrion models approximating human characteristics must be devised and investigated to evaluate studies focusing on fauna, habitat, and climate, on a regional geographic basis in the U.S. The public must be informed of the potential uses of forensic entomology in order for the benefits to be realized in the field.

The Appearance of Western Corn Rootworn Beetles, *Diabrotica virgifera virgifera,* on the Shores of Lake Michigan. Kurt P. Seevers, R.H. Grant, and

L.W. BLEDSOE, Dept. of Entomology, Purdue University, West Lafayette, IN 47907.——The annual occurence of western corn rootworm (wcr) beetles, *Diabrotica virgifera virgifera*, on the shores of Lake Michigan appears to be linked to weather and beetle behavior. Our research has shown that cold fronts are responsible for depositing the beetles on the lake surface and eventually on the beaches. Based on wind trajectory analysis, northwest Indiana is one likely source for the beetles. The majority of the beetles washed ashore are live females. Dissections have shown these beetles to have well developed fat bodies and to contain only moderately developed eggs. We believe that these females are making long duration preoviposition flights. Such flights have been described as an "oogenesis flight syndrome." Thus the wcr beetles seem to have evolved a propensity for long distance preovipositional flights that are aided by synoptic weather systems.

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POPULATION AND BEHAVIOR MODIFICATIONS OF SELECTED ARTHROPOD PESTS IN INDIANA DURING THE 1988 DROUGHT

TIMOTHY J. GIBB and LARRY W. BLEDSOE
Department Entomology
Purdue University
West Lafayette, Indiana 47907

INTRODUCTION

The severity of the 1988 drought throughout the Midwest may never be fully appreciated. Effects of the drought were felt throughout the State of Indiana. Agriculture was dealt a severe economic blow. Field crops died for lack of water, stock ponds dried up, cattle were sold for lack of feed to hold them over the winter, and arthropod pests infested field crops at an unprecedented rate. Incidence, behavior, and injury from many pests, including insects, was altered.

Populations of some agronomic pests were unusually high, and damage was severe. Other annual pests were conspicuously absent. Some health related pests were less of a nuisance during drought conditions. Others, though fewer in numbers, were more active and thus more commonly encountered. Injury from ornamental plant pests was compounded by the already drought weakened condition of the plants. Development of some insects of economic importance appeared to be more rapid than usual but was delayed in others.

Information about the incidence and behavior of pest arthropods in drought conditions for the most part is lacking in Indiana. This study seeks to fill some voids in those records.

METHODS

Trends presented in this study represent a summary of reports from the Insect Diagnostic Laboratory, survey results, National Weather Service data, a special inquiry telephone line, and other observations reported by the Department of Entomology at Purdue University. The Insect Diagnostic Laboratory serves Indiana clientele by identifying and recommending controls for anthropods or anthropod-related problems affecting plants or animals in the home, yard, or agronomic environments. The laboratory receives more than 1000 samples each year, usually through County Extension Agents. Many additional direct contacts are made through organized meetings and by telephone. Plant pest surveys, conducted through the Purdue University Extension Service, also provide much needed information concerning the development of many pests. A network of black light as well as pheromone traps maintained at critical locations throughout the State contribute to this effort. Field inspections at specific locations and times also aid as needed. Records of specific weather data from within the State is maintained and managed at the Midwest Agricultural Weather Service Center, West Lafayette.

A "drought hot-line" with a toll-free number was installed on 21 June at Purdue University. This service was designed to address questions from Indiana

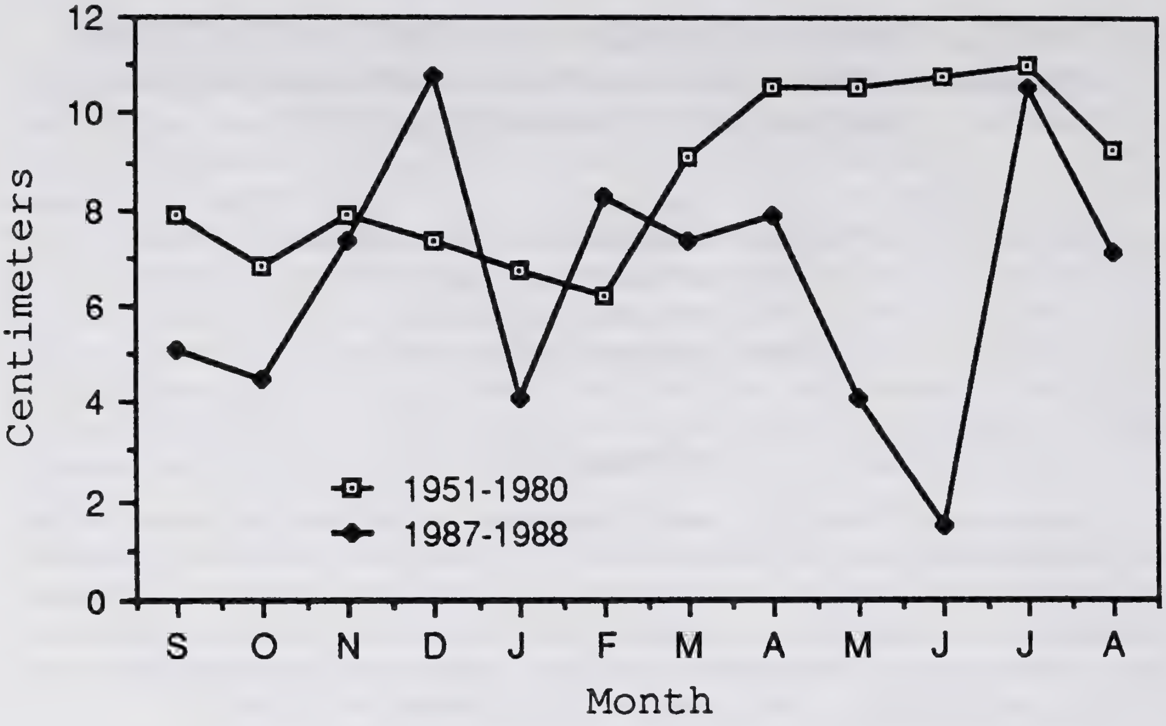

FIGURE 1. Indiana monthly precipitation averages.

residents about agriculture as well as how to deal with associated stress and financial problems caused by the drought in 1988. From 21 June to 21 October, the operators received approximately 4800 calls. Initially, 6-8% of the daily calls concerned entomologically related questions. However, as the drought continued and associated problems intensified in July and August, the Entomology Department received up to 50% of the calls (sometimes as many as 100 calls per day).

RESULTS

A comparison of 1988 precipitation records (State-wide monthly averages) with the average for the years from 1951 to 1980 indicates that until April, precipitation did not differ greatly from the 30 year average (Figure 1). April, May, June, and July, however, all had precipitation levels that were far below normal. Between 31 April and the 9 July, Indiana received less than 4 cm of precipitation (15% of normal). Lack of rainfall in the spring proved to be critical for agriculture. Many crops were planted into soil barely moist enough to germinate seed, much less support further plant growth.

Daily high temperatures, reported as monthly averages, also were substantially higher than the 30 year averages (Figure 2). During June, July, and August, temperatures averaged more than 3° C above normal.

PESTS OF AGRONOMIC CROPS

An estimated $50 million was spent for insect and mite control on agronomic crops alone in Indiana during 1988. Approximately $25 million more was lost due to crop damage resulting from those pests (personal comm., C. R. Edwards, Purdue University).

Spider mites (*Tetranychus* spp.) were Indiana's primary arthropod problem in 1988. Earlier than normal movement into fields from drying grasses and field

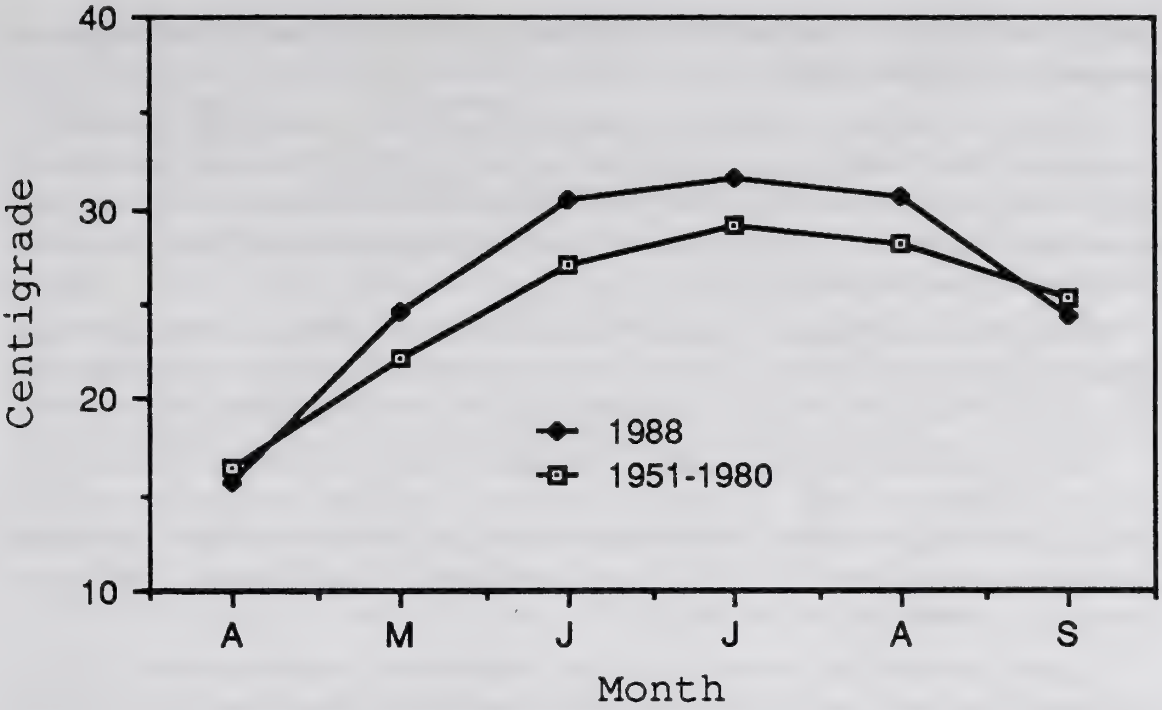

FIGURE 2. Indiana maximum temperature averages.

margins was reported by early July, when the already drought stressed plants were young. Soybeans were hit the hardest. Spider mite damage was so severe throughout most of the State that supplies of registered miticides became depleted. Miticides were shipped in from across the country to meet the demand. Twelve new 24-C (special local needs) registrations for miticides also were approved by the EPA to meet this emergency. An estimated 1 million acres of soybeans in Indiana were treated with miticides in 1988, many of which received multiple applications.

Bean leaf beetle (*Cerotoma trifurcata*), an important pest of soybeans, was also very prevalent this year. More concern was created than normal, because of the high numbers of beetles feeding on small plants already stressed by the drought.

Mexican bean beetle (*Epilachna varivestis*), a pest which has been steadily increasing in numbers and importance in Indiana over the past few years (Meyer, 1987), was not a major concern in 1988. Very few accounts of Mexican bean beetle either in field crops or home gardens were received, probably due to decreased survivorship of the larvae during the drought.

Corn rootworm (*Diabrotica virgifera virgifera*) was a pest on corn throughout the State this year. Higher temperatures early in the season increased their rate of development, causing first emergence of adult beetles slightly earlier than normal. Increasing soil temperatures apparently became too warm for optimum larval development by late June. As a result, even though first adults emerged somewhat earlier than normal, peak adult emergence was later than normal.

The drought may also have had an indirect effect on corn rootworms. Many rootworm insecticides that are applied at planting are dependent upon moisture to move them down into the root zone, where they protect roots from rootworm feeding. Lack of precipitation after insecticide application left insecticides suspended near the soil surface. Drought was implicated in several instances of rootworm insecticide failure.

European corn borer (*Ostrinia nubilalis*) was not a significant concern to growers in 1988. Moths began to fly when expected in 1988. However, the intense heat accompanying the drought may have interfered with normal mating and egg deposition. Fewer egg masses were deposited than normal, and those that were oviposited often desiccated.

Black cutworm (*Agrotis ipsilon*) moths arrived in Indiana about the same calendar date as in other years. However, reproduction and larval development were greatly hindered, because of the intense heat and drought of the early season.

Survival of grasshopper egg pods are known to be increased in dry conditions (Grace and Johnson, 1985). As expected, reports of increased grasshopper activity were received early in the season. However, significant grasshopper outbreaks and subsequent damage did not materialize. Survival and damage was low to moderate in most areas of the State.

In addition to mites, insects which suck plant juices, including thrips, aphids, and scales, tended to be greater pests this year than normal. Not only do those insects have direct access to water (through the plant), but they may benefit in two other ways as well. Plants under stress are known to limit production of natural chemical insect defenses and channel those nutrients to more basic life sustaining functions. This offers sucking insect pests an unrestricted avenue of attack. During stressful conditions (such as drought), new plant growth also has more concentrated proteins. This may directly benefit herbivorous insects, which are dependent on protein for growth and reproduction.

Alfalfa surveys indicated that potato leafhopper (*Empoasca fabae*) arrived on schedule as compared with 1986 (Meyer, 1987), but unlike other sucking insects, they never developed to economic populations, while the weather remained dry. Incidences of severe localized damage were reported, after significant precipitation was received in August, however.

The grape colaspis (*Colaspis brunnea*) beetle in soybeans caused isolated damage in 1988, whereas in other years, it was either insignificant or a very minor pest.

Significant outbreaks of chinch bugs (*Blissus leucopterus leucopterus*) were anticipated but did not occur. False chinch bugs (*Nysius raphanus*) were very common in many parts of the State and often were reported moving in very large numbers. Some growers did apply insecticides for this insect, even though little damage to cultivated plants was documented.

Complaints of Indian hempworm (*Pyrausta futilalis*) were common this season. This increase can be indirectly attributed to the drought. Lack of precipitation hampered the performance of many herbicides this year. More weeds (especially dogbane, the insect's primary host plant) occurred in cultivated fields. When these weeds dried down, the higher populations of hempworm began to migrate in large numbers, which led to more encounters and thus complaints from people. Again, little damage due to the feeding of this insect was documented.

The drought may have an indirect effect on future insect management in stored grain. Much of the grain harvested this fall was highly variable in condition, size, and moisture content. Unless artificially dried to a uniform moisture, Indiana growers may expect localized damp spots to develop in the grain mass, which may mold, heat, and create hot spots favorable to insect development and continued moisture buildup.

PESTS OF MAN AND ANIMALS

Generally, biting/stinging pests populations were reduced due to the drought. Social wasps and bees depend upon water to survive and to cool their colonies. Fewer naturally occurring water sources forced wasps and bees to search further and to expend more energy in search of this vital resource. Increased complaints of wasps and bees encountered at swimming pools, bird baths, etc. resulted even though actual numbers of these insects probably were reduced this year.

Mosquitos, which must have standing water to reproduce had very limited populations, especially in the early spring of 1988. If these were any positive effects found in the drought, this was probably it for most Hoosiers.

Flea larvae did not survive well out of doors in 1988. Flea complaints to the diagnostic laboratory were minimal. Tick reports were more prevalent than usual this spring. The heat and drought stresses may have caused ticks to be more active than usual. Recent news accounts of Lyme disease and Rocky Mountain Spotted Fever also may have increased public consciousness of ticks producing more reports than normal. Long term implications of the drought may be that the tick will have increased it's range in 1988, because primary host animals (deer and rabbits) increased their ranges in search of food and water (personal comm., R. Williams, Purdue University).

Other livestock pests, in particular face flies (*Musca autumnalis*) and horn flies (*Haematobia irritans*), decreased in number by mid summer. Horn fly populations recovered in numbers by the end of the summer, whereas face fly populations did not. Incidence of confinement flies was lower than most years, likely a direct result of the decreased availability of breeding sites and lower humidity.

PESTS OF ORNAMENTAL PLANTS

Drought-stressed trees and shrubs are less able to tolerate defoliating insects, such as caterpillars, sawfly larvae, and beetles. Continued stress will weaken even large trees, making them more attractive and vulnerable to bark beetles and wood borers (Schultz, 1983).

Eastern tent caterpillar (*Malacosoma americanum*) was a very common pest in the early spring of this year. Whether or not their increased occurrence was drought related is debatable. What is significant is that the trees' complete recovery from early season defoliation was clearly hindered by later drought stresses.

Annual white grubs' (Japanese beetles (*Popilia japonica*) and northern masked chafter (*Cyclocephala borealis*)) adult emergence was later than normal in 1988. High soil temperatures during late larval development were credited for this delay. Shortly before peak emergence (early August), enough precipitation fell in most areas of the State to bring most lawns out of drought induced dormancy. This fortuitous rain may have diluted the potential severity of concentrated attack by white grubs on green irrigated lawns. Some insecticide failures this year were linked to the facts that many grubs remained deep in the soil to avoid heat and water stress, chemicals were not moved down into the root zone (Niemczyk and Krueger, 1987), and chemicals broke down more quickly in the intense heat and sunlight. Fewer problems with adult Japanese beetles were reported this year either in the home yard and garden or agronomic crops.

Complaints of outdoor ants invading homes (probably in search of water) were more common in 1988 than in other years. Few complaints of carpenter ants (*Camponotus* spp.)) were reported.

Boxelder bugs (*Leptocoris trivittatus*) were an unusually common pest in 1988. Nymphs and adults of the first generation began entering homes in July. In most years, the first generation remains out of sight in the trees, and only the second generation becomes a problem from late August through October.

BENEFICIAL INSECTS

Survival of most beneficial insects, parasites, and predators was negatively affected by the drought. Honey bee (*Apis mellifera*) survival and honey production was variable and dependent upon specific geographical location. Some flowers are known to produce more nectar in drought conditions, while others produce less (personal comm., W. Fischang, Purdue University). Actual production of honey seemed to be closely correlated with proximity to certain flower species. In general, however, even bee colonies supplemented with water and food reserves through the drought were probably stressed, because of higher than normal temperatures.

SUMMARY

Drought in 1988 elicited species specific effects from arthropod populations in Indiana. Lack of water and breeding sites limited the survival and reproduction of many annual pests. Pests which have piercing-sucking mouthparts tended to do very well in the drought and were by far the most serious group of pests of 1988. High temperatures accompanying the drought both increased and retarded the development of insects depending on their stage of development and the temperatures attained. Overall, high temperatures increased stress and decreased survival of most insect populations.

It is difficult to predict how the drought of 1988 will affect future pest populations. Generally, grain harvested in 1988, unless artificially dried, is expected to be in a condition conducive to attack by stored grain pests. Drought stressed and weakened shade trees and shrubs were stressed sufficiently to increase their susceptibility to wood borer and bark beetle damage in the coming seasons.

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TRYPSIN ACTIVATION OF THE *BACILLUS THURINGIENSIS* DELTA-ENDOTOXIN IN *OSTRINIA NUBILALIS* LARVAE

D.B. Rivers, C.N. Vann, and H.L. Zimmack
Department of Biology
Ball State University,
Muncie, Indiana 47306

INTRODUCTION

The aerobic spore-forming soil bacterium, *Bacillus thuringiensis* (Bt), is well known for its ability to produce a proteinaceous parasporal crystal during sporulation (Eller, *et al.*, 1985; Jaquet, *et al.*, 1987). This crystal protein is toxic, following ingestion, to many insect larvae from the orders Lepidoptera, Diptera, and Coleoptera. After exposure to the alkaline conditions within the insect gut, the crystalline protein (230 kda) is reduced to a 130 kilodalton (kda) protoxin, which is then converted to the activated toxin (55-68 kda) by proteolytic action of the insect gut proteases.

Bacillus thuringiensis strains are grouped into subspecies based on antigenic properties of the flagella and biochemical characteristics (Jacquet, *et al.*, 1987). More than 30 subspecies have been characterized to date. Most of these subspecies are toxic to lepidopteran larvae, while one subspecies is specific for mosquitoes and blackflies. Partly because of their potential as biological insecticides, the study of these delta-endotoxins is of extreme commercial and scientific interest.

The delta-endotoxins of *Bacillus thuringiensis* differ in their activity and potency toward different insect species. The reasons for these differences are not known. However, several factors may be involved, since the crystal protein has to pass through a two-step process, solubilization and activation, before reaching the gut epithelium, where the toxin appears to act (Jacquet, *et al.*, 1987). An alkaline gut pH and proteases of the insect gut have been reported as being potential factors that govern this two-step process and thus the specificity of these delta-endotoxins (Jacquet, *et al.*, 1987; Luthy, *et al.*, 1987). Recent studies by Ellar, *et al.* (1985; Knowles, *et al.*, 1984) indicate that glycoprotein receptors on the insect gut epithelium play a role in determining potency and specificity of *B. thuringiensis* delta-endotoxins. However, their findings also revealed that binding of the delta-endotoxin to the gut epithelium is at least partially controlled by the insect gut environment, i.e. pH and gut proteases.

This paper represents an attempt to assess the role of insect gut juices in determining specificity and potency of two *Bacillus thuringiensis* delta-endotoxins. For this study, larvae of an insect considered not susceptible to Bt delta-endotoxins, *Ostrina nubilalis* Hbn. (European corn borer), were selected to assess the ability of gut proteases and pH to regulate the potency of *B. thuringiensis* Berliner and *B. t.* var. *kurstaki* HD-73 delta-endotoxins. Larvae of the corn borer have demonstrated almost no susceptibility to the delta-endotoxins of either of these strains. Rivers and Zimmack (unpublished data) have observed that the pH (6.8-7.2) of corn borer larval gut juices is not favorable for solubilization of Berliner and HD-

73 delta-endotoxins, which may account for the low susceptibility of corn borer larvae toward these endotoxins.

In order to determine whether the pH found in the gut contents of corn borer larvae is a factor governing the potency of Berliner and HD-73 delta-endotoxins, the pH of corn borer larvae gut contents was adjusted to that found in highly susceptible insects (9.5-11.0), and the gut juices were incubated with crystals from both Bt varieties. The concentration of proteolytic enzymes in the gut contents was also altered, and observations of changes in the solubilization or activation of crystals from Berliner and HD-73 were noted. Sodium dodecyl sulfate gel electrophoresis (SDS-PAGE) was used to monitor solubilization (protein band at 130 kda) and activation (band at 55-68 kda) of the crystals from both Bt varieties incubated with gut juices from corn borer larvae. A protein band of 230 kda was observed, if neither solubilization or activation occurred. Bioassays were performed to determine whether alterations to the gut pH and/or concentration of proteases in the gut juices would effect the susceptibility of corn borer larvae toward crystals from Berliner and HD-73. Corn borer larvae displayed a high susceptibility to crystals incubated in gut juices that had been altered with the addition of a proteolytic enzyme and the pH adjusted to 10.2.

MATERIALS AND METHODS

Bacterial strains and growth conditions. *B. thuringiensis* var. *kurstaki* HD-73 was supplied by D.H. Dean (*Bacillus* Genetic Stock Center, Columbus, Ohio) and maintained in the laboratory on nutrient agar slants. *B. thuringiensis* Berliner was isolated from a refrigerated Dipel formulation (Abbott Laboratories, North Chicago, Illinois) and maintained as above. Both subspecies were grown in half strength BBL nutrient broth medium at 30°C for 4 days on a rotary shaker.

An *Escherichia coli* strain (JM103) containing the plasmid pOS4201, which produces the C protein (Kronstad and Whitley, 1986) from *B. thuringiensis* var. *kurstaki* HD-1, was obtained from the *Bacillus* Genetic Stock Center and maintained on minimal media slants. This plasmid encodes a 130 kda protein, which is believed to be the protoxin derived from intact crystal of *kurstaki* HD-1. In order to obtain protoxin, plasmid pOS4201 was grown in Luria broth medium containing ampicillin (100 μg/ml) at 37° C for 24 hours. Isopropyl-beta-D-thiogalactopyranoside was added (5×10^{-5} M) to induce the *lac* promotor to produce the 130 kda protein.

Isolation and purification of crystals. The crystals were separated from the spores by a two-phase system with dextran sulfate and polyethylene glycol (Goodman, *et al.*, 1967). The crystal suspensions, containing less than 1% spores, were stored frozen at -20° C. Protein from pOS4201 was isolated by sonication of the cells five times for 30 seconds at the maximum setting using a Sonic Dismembrator (Quigley-Rochester). The resulting suspension was centrifuged in 12% NaBr at 3500 x g, and the crystals were washed twice by centrifugation at 3500 x g in distilled water at 4° C. The protein suspensions were stored frozen at -20° C.

Preparation of gut enzyme. Gut proteases were prepared by removing the digestive tracts of 12 fifth-instar corn borer larvae and placing them in 50 mM carbonate buffer/HCL (pH 9.5) containing 10 mM dithiothreitol as a reducing agent. The guts were homogenized and then centrifuged at 10,000 x g for 5 minutes. The supernatant was stored frozen at -20°C.

TABLE 1. Bioassays using first instar European corn borer larvae fed crystals from *B. thuringiensis* Berliner and *B.t.* var. *kurstaki* HD-73.

		Mortality	
Strains	**24 hours**	**48 hours**	**72 hours**
Bt Berliner untreated	315	32%	74%
Bt Berliner treated	84%	100%	100%
Bt *kurstaki* HD-73 untreated	46%	54%	75%
Bt *kurstaki* HD-73 treated	92%	100%	100%
pOS4201 untreated	36%	41%	41%
pOS4201	62%	62%	62%

* Intact Bt cells containing spores and crystals were used as well as crystal alone to observe the effects of trypsin activation at pH 10.5. Cell concentrations used were 1 x 10^8 cells/ml; crystal concentrations were 9.0 µg/ml of liquid food medium. One hundred first instar larvae were used at each concentration.

Solubilization of crystal into protoxin. The crystals were solubilized by the method of Thomas and Ellar (1983). Solubilization was also performed by incubating the crystals in gut enzymes at 37° C for 60 minutes. The insoluble fraction was removed by centrifugation (10,000 x g) for 5 minutes, and the supernatant stored at -20° C.

Preparation of active toxin. Protoxin was incubated with trypsin (2.8 mg/ml) or gut enzymes (10:1 w/v) for 30 minutes at 37° C for sodium dodecyl sulfate polyacylamide gel analysis (SDS-PAGE). For insect bioassays, crystals were incubated for 30 minutes at 30° C with trypsin (2.8 mg/ml) at a pH of 10.2.

SDS polyacrylamide gel electrophoresis. SDS-PAGE was performed by the method of Knowles, Thomas, and Ellar (1984).

Insect larvae and bioassays. Newly hatched first instar European corn borer larvae were used for the bioassays. Corn borer egg masses were supplied by the USDA-ARS, Ankeney, Iowa. Bioassays were performed by the method of Reichelderfer (1987). Crystals, protoxin, and toxin were mixed with the liquid diet at 60° C; the mixture was then poured into sterile shell vials and allowed to cool. A single, newly hatched larva was placed in each vial. Mortality was determined after 3 days incubation at 29° C.

RESULTS

Table 1 contains data collected from bioassays that exposed first instar European corn borer larvae to treated and untreated crystal protein from *B. t.* Berliner, *B. t.* var. *kurstaki* HD-73, and the plasmid pOS4201. Bioassays that used native crystals (untreated) taken directly from Berliner, HD-73, and pOS4201 demonstrated relatively low morality (32-54% after 48 hours), when crystals were fed to larvae of the corn borer. Treated crystals (preincubated at a pH of 10.2 with 2.8 mg/ml trypsin) from Berliner, HD-73, and pOS4201, however, displayed insecticidal activity toward the corn borer that is typical of the activity found in highly susceptible insects (Sutter and Raun, 1967). Mortality reached 100% in larvae fed treated crystals from Berliner and HD-73 within 48 hours, while treated crystals from the plasmid pOS4201 induced only 62% mortality after 96 hours.

SDS-PAGE was used to determine whether crystals from Berliner, HD-73, and the plasmid pOS4201 were activated or solubilized. Preliminary SDS-PAGE data (not shown) revealed that crystals from Berliner and HD-73 incubated in gut enzyme from corn borer larvae for 2 hours were solubilized but not activated in the existing gut conditions. A protein band observed at 130 kda from crystals of Berliner and HD-73 indicated that the crystals from both varieties had been solubilized. The appearance of a protein band in the 55-68 kda range would have indicated that the crystals from both varieties had undergone both solubilization and activation. However, a protein band in this range was not observed for crystal protein from Berliner and HD-73. Crystal protein from the plasmid pOS4201 was neither solubilized nor activated, when incubated in corn borer gut enzyme. A band at 130 kda was observed after incubation in corn borer gut enzyme. Since this plasmid encodes only crystal protein in the protoxin form (130 kda), solubilization was not expected. However, activation was expected to occur due to the proteolytic action of corn borer gut proteases.

Crystals from Berliner and HD-73 were further examined by presolubilizing the crystal protein before incubating with gut enzyme. This was accomplished by incubating the crystals in a carbonate buffer containing the reducing agent dithiothreitol at a pH of 10.2. SDS-PAGE data revealed that the crystals from both Berliner and HD-73 formed a major band at 130 kda, indicating that the crystals had been solubilized. These presolubilized crystals were then incubated with corn borer gut enzyme for 1 hour. Using SDS-PAGE, a protein band was observed at 68 kda (not shown) for both Berliner and HD-73 crystals. This observed protein band at 68 kda indicated that the crystal protein from both varieties had been activated by the corn borer gut proteases.

DISCUSSION

Larvae of the European corn borer have been reported as showing almost no susceptibility to the delta-endotoxins of *Bacillus thuringiensis* varieties Berliner and *kurstaki* HD-73 (Sutter and Raun, 1967). This study using native crystals from both varieties fed to first instar corn borer larvae (Table 1) confirmed the conclusions of Sutter and Raun (1967.). Several reports (Haider, *et al.*, 1986; Jaquet, *et al.*, 1987; Tojo and Aizawa, 1983) have indicated that the pH and composition of gut juices from insects highly susceptible to the delta-endotoxins of *Bacillus thuringiensis* play a part in governing potency and specificity of these endotoxins. This research addressed whether the lack of susceptibility that European corn borer larvae display toward Bt delta-endotoxins may be attributed, at least in part, to the pH and composition of gut contents found within these larvae.

Tojo and Aizawa (1983) previously determined that two gut factors are essential for solubilization and activation of *B. thuringiensis* crystals: 1) an insect gut pH of 10.2-10.5; and 2) gut proteases similar to trypsin-chymotrypsin. The highly alkaline gut pH found to be necessary for solubilization by Tojo and Aizawa (1983) has been observed in most highly susceptible insects tested thus far. European corn borer larvae possess gut contents with a pH near neutral (Raun, *et al.*, 1966; Rivers and Zimmack, unpublished) and appear to possess gut environments not capable of solubilizing Bt delta-endotoxins. SDS-PAGE data presented here agree with this observation.

Crystals from Berliner and HD-73 incubated in corn borer gut enzymes and subjected to SDS-PAGE both formed a major band at 130 kda. This would suggest that solubilization of the crystals to protoxin occurred, but the protoxin was not activated. This observation might be attributed to a lack of proteoltic enzymes within the gut contents. However, SDS-PAGE revealed that presolubilized crystals were transformed into the activated toxin, when incubated in gut juices from corn borer larvae. Therefore, it appears that corn borer larvae possess proteolytic enzymes capable of activating the protoxins derived from Berliner and HD-73 crystals. The inability of corn borer gut juices to convert the intact crystals of Berliner and HD-73 to the activated toxin appears not to be due to a lack of proteases in the corn borer gut. The lack of an alkaline gut pH appears to be responsible for the inability of corn borer gut juices to transform crystals into the activated form.

The gut proteases of certain Lepidopteran species have been observed to be capable of cleaving the intact crystal of Bt and releasing the 130 kda protoxin (Tojo and Aizawa, 1983). This suggests that the 130 kda bands observed by SDS-PAGE for crystals from Berliner and HD-73 may not have been solubilized by the pH conditions of the corn borer gut but rather by proteolytic processing of the crystals. This mechanism is supported by the observed protease activity in corn borer midguts discussed above and by the observations of Tojo and Aizawa (1983).

Observations by Jaquet, *et al.* (1987) suggest that larvae of *Heliothis virescens* (a nonsusceptible insect) are not good convertors of the intact crystals of Bt *morrisoni* into the activated toxin, apparently due to a lack of gut proteases. By incubating *morrisoni* crystals in a proteolytic enzyme before feeding the crystals to *H. virescens* larvae, mortality was induced that resembled that of a highly susceptible insect. These larvae possess a gut pH between 9.0-10.2, so the concentration of proteolytic enzyme within their guts appears to be the limiting factor for the activation of Bt crystals.

With *Heliothis virescens* larvae, both gut factors described by Tojo and Aizawa (1983) had to be met for mortality to be induced that resembled that of a highly susceptible insect. Both gut factors appear to be required for corn borer larvae as well. Since the required proteases appear to be present, it seems that the neutral pH found within the gut juices of European corn borer larvae is not favorable for solubilization and is the limiting factor for the activation of the crystals of Berliner and HD-73.

The protein crystals produced by the plasmid pOS4201 were neither solubilized nor activated when incubated in corn borer gut enzymes. Solubilization was not expected to occur, since this plasmid only produces crystals in the 130 kda protoxin form. However, activation of the 130 kda protoxin was expected to occur due to the apparent proteolytic activity observed in the corn borer's gut contents using crystals from Berliner and HD-73. Since only one band of 130 kda was observed after two hours incubation in the gut contents of corn borer larvae, it appears that corn borer larvae lack the proteases necessary to activate the crystals produced by the plasmid pOS4201. However, as discussed above, corn borer gut contents appear to possess proteases capable of activating solubilized crystals from Berliner and HD-73. Perhaps, some other factor is involved in the solubilization and activation of the protein products from the plasmid pOS4201, or the amount of proteolytic enzyme required to induce activation of the crystals *in vivo* (bioassays) is much higher than that needed for *in vitro* (SDS-PAGE) studies. Bioassay data in Table 1 would appear to support the latter possibility.

Data obtained from bioassays revealed that crystals from Berliner, HD-73, and the plasmid pOS4201 required incubation with a proteolytic enzyme (trypsin) in an alkaline environment (pH 10.2) to induce 100% mortality in corn borer larvae. This seems to conflict with our SDS-PAGE observations which suggest that adjusting the pH of corn borer gut juices to 10.2-10.5 should induce high mortality with crystals from Berliner, HD-73, and the plasmid pOS4201 incubated in these gut juices, when fed to corn borer larvae. A third factor in the gut of Lepidoteran insects has been suggested to be involved in regulating potency of Bt delta-endotoxins and may play a role in our conflicting data between SDS-PAGE and bioassays.

Recent studies by Ellar, *et al.* (1985; Knowles, *et al.*, 1984) have suggested that glycoprotein receptors on the insect gut epithelium may be a third factor, aside from gut pH and proteases, governing potency of *B. thuringiensis* delta-endotoxins. However, these cell receptors would not be a factor in the solubilization and activation of Bt crystals. Therefore, glycoprotein receptors on European corn borer gut epithelium did not play a role in the inconsistencies observed between our SDS-PAGE observations and bioassay data. Differences in the concentration of gut proteases required to activate solubilized crystal for *in vitro* and *in vivo* studies may account for the need to add trypsin to altered gut contents (pH adjusted to 10.2) of corn borer larvae to induce high levels of mortality. Studies are currently being conducted in our laboratory to further examine this possibility.

This study suggests that the transformation of *Bacillus thuringiensis* crystals into the activated toxin depends upon the insect gut environment. Solubilization of crystals from a given variety of *Bacillus thuringiensis* appears to be dependent upon the pH and possibily the proteases found within the insect gut. Our observations suggest that the European corn borer is not a good activator of the intact crystal into the solubilized form. This is important, since commercial preparations of *B. thuringiensis* are presented to the target insect in the form of the intact crystal. This work suggests that the effect of the delta-endotoxin may be increased toward a target insect by applying crystal that is transformable to the activated toxin within the insect gut or by directly applying the activated toxin.

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OVIPOSITION PREFERENCE AND LARVAL DEVELOPMENT OF THE MOSQUITO SPECIES *AEDES TRISERIATUS* (SAY) IN ACIDIC WATER

H.F. Siewert
Natural Resources Department
Ball State University
Muncie, Indiana 47306

S.R. Madigosky
Biology Department
Widener University
Chester, Pennsylvania 19013
and
R.R. Pinger
Physiology and Health Science Department
Ball State University
Muncie, Indiana 47306

ABSTRACT: Effects of acidic water on oviposition preference, survival, and larval development of the mosquito species *Aedes triseriatus* (Say) were studied in the laboratory. Oviposition preference was assessed by allowing gravid females to deposit eggs on oviposition sites containing rainwater adjusted to pH 2, 3, 4, 5, 6, and 7. Results show that pH 2 and 3 were unfavorable for oviposition. However, mosquitoes laid eggs in water ranging from pH 4 through 7. A significant difference between selection of oviposition sites existed, when pH 2 and 3 were compared with pH levels 4, 5, 6, and 7 ($p < 0.01$). Larval development was assessed by allowing 50 first instar larvae to develop in separate glass containers at five levels (pH 3-7) and a control. Mortality was greatest at pH 3. At pH 4 and below, larval development was adversely affected.

INTRODUCTION

The increasing acidity of rain caused by the conversion of air-borne nitric and sulfur oxides to nitric and sulfuric acids has been of concern in North America for nearly two decades. Regions, which are susceptible to acidification, are those which have a low buffering capacity. In such areas, the threat of acidification has become especially apparent in freshwater ecosystems. Although the deleterious effect of acid precipitation on aquatic animals has yet to be fully evaluated, evidence shows that increases in hydrogen ion concentration are responsible for the decrease of several amphibian (Freda, 1986; Neville, 1979; Pierce, 1985) and invertebrate (France and Stokes, 1987; Sehgal and Pillai, 1970) populations.

There is a paucity of information on the effect of acid precipitation on the development of aquatic insects, particularly mosquitoes. Most studies on the effect of pH on mosquito biology are simply field observations reporting the occurrence and distribution of particular mosquito species in acidic habitats (Peterson and

Chapman, 1969; Sehgal and Pillai, 1970) or laboratory studies in which the toxicity of different acids is compared (Ingram, 1954; Kurihara, 1959; MacGregor, 1929; McGaughy, 1968; Pillai and Madhukar, 1969).

Aedes triseriatus (Say), sometimes called the eastern tree hole mosquito, is the primary vector of LaCrosse Encephalitis virus in the north-central United States. Its natural larval habitat is the water that collects in tree holes, tree crotches, or shaded tree stump holes. It also makes use of water that collects in automobile tires and to a lesser degree in tin cans and other artificial containers. Adult females are similar in appearance to another, less common tree hole mosquito, *Aedes hendersoni* (Cockerell) but can be separated with some difficulty using differences in color (Truman and Craig, 1968) and shape of tarsal claws (Harmston, 1969). Larvae and males are very difficult to identify from each other.

Both *Ae. triseriatus* and *Ae. hendersoni* can be distinguished easily from the recently introduced Asian tiger mosquito, *Aedes albopictus* (Skuse). The latter has a distinct white stripe extending along the middle of the back from the anterior margin of the scutum nearly to the scutellum. The remainder of the thorax is dark. The legs of the Asian tiger mosquito are brightly marked with bands of white scales, absent in *Ae. triseriatus* and *Ae. hendersoni.*

Unlike previous studies, our investitagtion was designed to 1) determine the effects of pH on the oviposition response and to 2) continuously monitor the effects of various concentrations of sulfuric acid on larval survival and development. Since sulfuric acid comprises 70% of the acid rain in the eastern United States, adults and larval *Aedes triseriatus* were exposed to various concentrations of this acid.

MATERIALS AND METHODS

Colony establishment and maintenance: *Aedes triseriatus* larvae were collected from discarded tires in Muncie, Indiana and reared in the laboratory. Larvae were fed finely ground Tetra Min fish food daily. Pupae were transferred to 60 X 60 X 60 cm cages in which the adults emerged. These adults were provided with a 10% sucrose solution, which was removed 24 hours before bloodfeeding. Blood meals were provided by an anesthetized guinea pig. Eggs were collected on black cloth and were held for 14 days under conditions described below to permit adequate time for embryonation. They were then placed in a hatching medium composed of a 1:1000 solution of nutrient broth and distilled water. Experimental work was restricted to the 3rd generation raised in captivity.

Mosquitoes were maintained at 23 ± 2°C, 75% ± 3% RH, and a photoperiod of 15 hours of daylight per 24 hours. Fluorescent lamps controlled by a timing device provided a 14.25 h intensive light period. A rheostat attached to a clock decreased incandescent light intensity between photophase and scotophase.

This study was divided into two phases. In the first phase, oviposition site selection at pH levels 2, 3, 4, 5, 6, and 7 was determined. The second phase was a study of larval development time as well as pupation and emergence success at pH levels 3, 4, 5, 6, 7, and control.

Oviposition preference. Sixty 0.47-liter cylindrical paper containers were used to hold individual female *Ae. triseriatus* mosquitoes. The center portion of the lid was removed and replaced with mosquito netting. Six equally spaced holes,

TABLE 1. Percent mortality of mosquito larvae exposed to pH 3, 4, 5, 6, 7, and control (N = 50 at each pH level).

pH level	Instars				Pupae	Total %
	1	2	3	4		
3	36	64	0	0	0	100
4	12	28	4	0	0	44
5	10	10	0	0	2	22
6	0	10	0	2	2	14
7	2	6	0	0	6	14
Control	0	6	0	0	4	10

1.8 cm in diameter, were punched in the bottom of each container. Each hole accommodated a glass vial (7 cm he. x 1.8 cm I.D.), which served as the water reservoir. Each vial contained water previously adjusted to one of six pH levels (2-7) and a presoaked balsa wood strip which served as an oviposition site. The acidity of the water was increased with sulfuric acid or decreased with calcium oxide.

Sixty gravid females were then transferred to the 0.47 liter containers, one female per container allowing each gravid female a choice of oviposition sites at six different pH levels. These cages were rotated daily to prevent mosquitoes from establishing location preference. A fresh cotton ball soaked in 10% sucrose solution was placed on top of each cage daily.

After oviposition, the mosquitoes were removed from the cages and each balsa-wood strip examined for the presence of eggs. If one or more eggs were observed on the strip, the oviposition response was recorded as positive. Data were analyzed to determine statistical significance of oviposition preference for specific pH levels using the Cochran Q-test (Siegel, 1956).

Larval development. Three hundred newly hatched, third generation, 1st instar larvae were placed in 120-ml glass jars, one larva per jar. Each jar contained rainwater previously adjusted to one of five pH levels: 3, 4, 5, 6, or 7. Fifty individuals were exposed to each pH treatment level and a control treatment. Hydrogen ion concentration in each jar was measured daily with a pH meter. When a change in pH was observed, the solution was readjusted to the original treatment level. The exception was the control treatment consisting of ambient rainwater with an initial pH of 5.6 After larval food was added, the pH increased to 7.5 and remained at that level for the remainder of the study.

Mortality, molting, pupation, and emergence of adults were recorded daily. A two-way analysis of variance was used to determine differences in mortality of groups at different pH levels and to assess differences in larval development time at various pH levels.

RESULTS AND DISCUSSIONS

Mosquitoes did not oviposite on balsa wood in water with pH of 2. Only one cluster of eggs was found at pH 3. However, clusters of 11, 16, 12, and 13 were found at pH 4, 5, 6, and 7, respectively. Similar results were obtained by Pillai

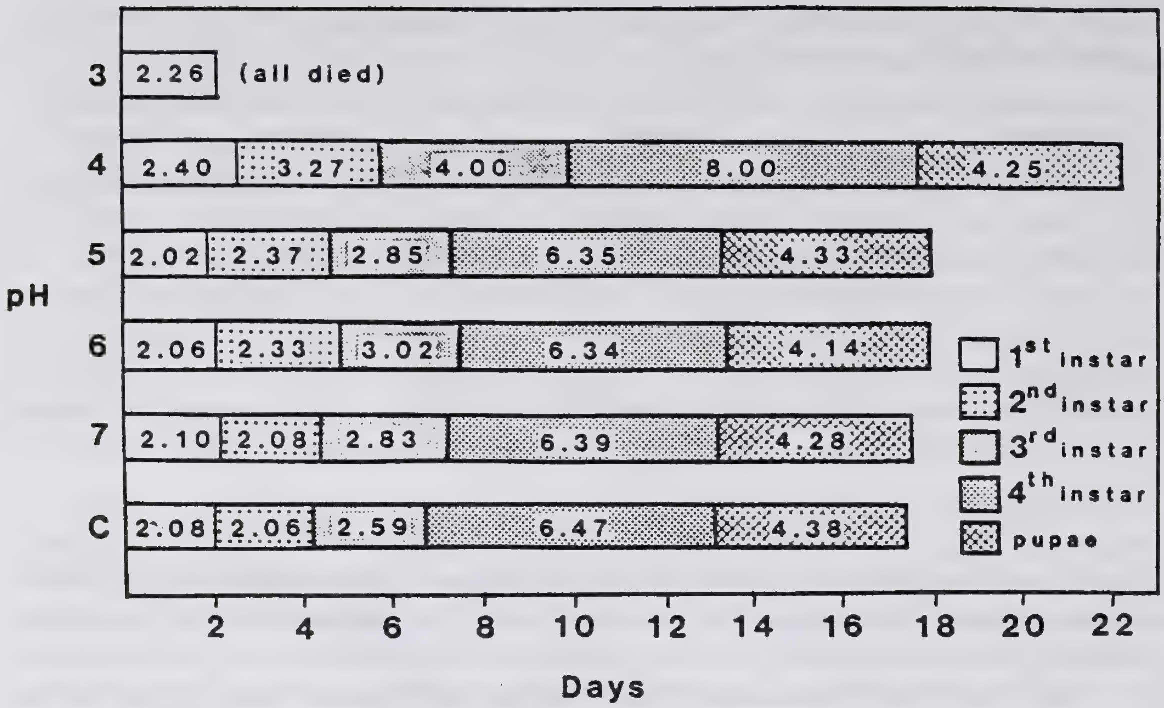

FIGURE 1. Average number of days required by *Aedes triseriatus* to complete instars 1, 2, 3, 4, and pupal stage at pH levels 3, 4, 5, 6, 7, and control.

and Madhulear (1969), who observed the lowest number of *Ae. aegypti* eggs at pH 2. Although no significant differences between responses at pH 4, 5, 6, and 7 were found, these levels were significantly higher than those at pH 2 and 3 ($p < 0.01$). The failure of mosquitoes to respond to oviposition sites at pH 2 and 3 suggests that highly acidic substrates are avoided by gravid *Ae. triseriatus* females.

When *Ae. triseriatus* were reared in media at pH 3, 4, 5, 6, and 7, mortality increased with increases in hydrogen ion concentration (Table 1). No larvae survived past the second instar in water at pH 3. Differences in mortality at pH 4, 5, 6, 7, and control were not statistically significant. However, the Cochran Q-test indicated a significant difference in mortality between groups raised in water at pH 4 and 5 ($p < 0.05$). The difference in mortality between larval groups reared at pH 3 and 4 was highly significant ($p < 0.001$). These data indicate a marked detrimental effect on larvae in water between pH 4 and pH 5. Similar results were obtained by Ingram (1954) and Tomkiewicz and Dunson (1977), who studied various aquatic insects. In this study, many of the deaths of mosquito larvae occurred during ecdysis.

Clements (1963) suggested that the fluid which digests the inner layers of the old cuticle may be altered by a high hydrogen ion concentration, inhibiting ecdysis and subsequently resulting in death. Mosquitoes in the early stages of development appeared most affected by highly acidic conditions. At lower pH levels (3, 4, and 5), most mortalities were observed at the first and second instar stages. Apparently, the body resistance to hydrogen ions increased with age. Craig and Clark (1938) found the buffer value of the larval blood in *Pieris rapae (L.)* and *Heliothis obsoleta (F.)* to be greatest in the last instar. Furthermore, Hoskins (1932) suggests that mosquito larvae are more affected by acidity then pupae, because the lining of the larval digestive tract is more permeable than the outer covering of the pupae.

A summary of the time required by *Ae. triseriatus* from hatching to emergence of adults is presented if Figure 1. Times required for completion of instars 1, 2, and 3 were significantly longer at pH 4 than at higher pH levels ($p < 0.05$). Fourth instar larvae also required a longer period for development at pH 4, but this difference was not statistically significant. Similarly, no significant differences between stages at other pH's or between duration of pupal stages were found.

Observations from this study indicate the *Ae. triseriatus* is adversely affected by excessive hydrogen ion concentration derived from sulfuric acid, a major constituent of acid rain. The data suggest that this species may be restricted in growth and development, if the pH of ambient breeding water falls below pH 4. Similarly, a decrease in pH may limit the distribution of this species by rendering potential breeding sites unsuitable for oviposition.

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NOTES ON INDIANA WATER BEETLES

Frank N. Young
Department of Biology
Indiana University
Bloomington, Indiana 47405

ABSTRACT: *Hydroporus republicanus republicanus* Sharp is reported from Indiana along with *Gyrinus marginellus* Fall. The latter may be the *Gyrinus limbatus* of Thomas Say, 1823. Notes are given on the occurrence of *Hydroporus deflatus* Fall in Indiana and elsewhere. This species may be the *Hydroporus corvallis* of Fall. The type of *Dineutus ciliatus* (Forsberg) described from the East Indies bears a simple label "Ind.," which probably indicated Indiana. The species is common in woods and streams in southern Indiana and occurs widely over the eastern United States.

Several years ago while working in the British Museum (Natural History) in London, I came to the conclusion that *Hydroporus republicanus* Sharp (1882) was the same as specimens from Louisiana, Georgia, and Florida. Specimens from the latter two States were with few exceptions strongly melanized and fit closely the description of *Hydroporus effeminatus* Fall (1923) from Levy County, Florida. Later, comparison of specimens with Fall's types in the Museum of Comparative Zoology (MCZ) at Harvard University confirmed this conclusion.

Typical *republicanus* was not recognized from Owen County, Indiana, in Young's 1978 paper (description of *Hydroporus psammodytes* Young). However, it occurs abundantly in the marginal vegetation and debris of Fish Creek west of Freedom and has since been taken in Brown County (Goodley Branch near Belmont) and Monroe County (margin of stream east of Bloomington). It probably occurs widely in the eastern United States. *Hydroporus* comparable to *effeminatus* Fall occur abundantly in Florida and southern Georgia. They are nearly identical with typical *republicanus* except for their much darker coloration. They should be referred to *Hydroporus republicanus effeminatus* Fall (new combination).

Both subspecies are distinguishable from the rest of the *Hydroporus undulatus* complex by their size (3.0-3.9 mm total length), the narrow anterior tarsi of the males, the very smooth surface in the males which Fall considered practically impunctate, and the reduced but distinctive sub-basal and post median fasciae of light spots on the elytra. The latter are usually detectible even in the most heavily melanized specimens of *effeminatus*. The male genitalia are of the usual *undulatus* type and not especially noteworthy. The character of the pronotal border emphasized by Fall in the description of *effeminatus* is difficult to assay at best. Once recognized, *republicanus* in its typical form and the dark *effeminatus* are easily distinguished from other members of the group.

Hydroporus deflatus Fall was described from Virginia and New York (Fall, 1923). It is a member of the *Hydroporus oblitus* group, whose members are semi-subterranean in the gravel beds of springs and small streams. They retreat into the gravel when the water is low and reappear upon flooding. *H. deflatus* is easily distinguished from the other species in the group by its larger size (total length 3.5 to over 4 mm) and distinctive male genitalia. The species is widely distributed from New York to Indiana, south to Florida. It may also be identical with *Hydroporus corvallis* Fall (1923) known (as far as the author can determine) from a single female from Corvallis, Oregon.

Specimens of *H. deflatus* have been seen in the following localities: Glencaryn, Alexandria County, Virginia, Ernest Shoemaker collector (type in MCZ); Staten Island, New York, J.D. Sherman collection, New York State Museum; Pennsylvania, Crawford County, Pymatuning State Park, rain gauge, F.N. Young collector in FSCA; Tennessee, Robertson County, pond west of Hubertsville, G.W. Wolfe collection in FSCA; Maryland, Edgewood, H. Dietrich collector in Cornell University collection; Indiana, Brown, Jackson, and Monroe Counties, F.N. Young collector in Purdue University, Laboratory of Insect Diversity, and FSCA; Florida, Columbia County, near Lulu, F.N. Young collector, recorded as *Hydroporus* (*s. str.*) *dichrous* Melsheimer?, in Young (1954); Florida, Suwanee County, Suwanee State Park, black light trap, J.R. Wiley collector in FSCA.

Gyrinus marginellus Fall was described from New Jersey without any indication of habitat preferences. K.F. Chamberlain (1929), however, described the sort of situations in which the author has also found *marginellus*, along with *Gyretes compressus* LeConte and *Dineutus ciliatus* Forsberg, in Greene and Owen Counties, Indiana. These species are presumably nocturnal in habits and normally seek out the darkest areas in their habitat. *Ciliatus*, for example, has been found not only under undercut stream banks, but also under log rafts in streams in Owen County. In Florida, a long series of *Gyretes iricolor* Young was found near the type locality in Holmes County under banks as described by Chamberlain. The *Spanglerogyrus* recently described from Alabama may also be a nocturnal creature, the diurnal habitat of which is in deeply shaded or dark situations. Other species of the Gyrinidae may also be abundant in such situations and are rare in collections only because night collecting is not common.

In June, 1981, a large number of *Gyrinus marginellus* was found in small pools beneath undercut banks in Bay County, Florida, supporting the suspicion that this may be *limbatus* of Say.

Gyrinus marginellus is fairly easy to distinguish from other species of *Gyrinus* by its size (total length 3.9 to 4.5 mm), the reddish brown venter, the highly polished surface of the pronotum and elytra particularly in males, and the broadened apex of the male aedeagus. The only species with which it is apt to be confused is *Gyrinus elevatus* LeConte, which has a very distinctive narrowing of the male adeagus and is relatively rare outside Florida.

Gyrinus piceolus Blatchley remains a rather rare beetle in Indiana or elsewhere. The localities remain the same as cited in Young (1953): Lake County, Indiana (Type locality); Lafayette, Indiana, and Washtenaw County, Michigan (specimens in Purdue University, Laboratory of Insect Diversity). This species also may be nocturnal in habits.

Dineutus ciliatus Forsberg was reported by Young in 1978. The discovery of the beetle in Indiana was due to the diligence of Darwin and K.K. Kinney of Freedom, Indiana. They discovered the species in Fish Creek west of Freedom in the 1950's. The confirmation through examination of the male genitalia, however, did not come for some years afterwards. The beetles occurred around a log raft which formed near the bridge over the creek at Goose Creek Road and were common only under and near this mass of logs. In the 1980s, the raft broke up and was dispersed by flooding. *Dineutus ciliatus*, however, was found in small schools where the raft had been for some years afterwards.

It is interesting that *Dineutus ciliatus* was described from the East Indies. The type specimen (in the Thunberg Collection in the museum in Upsala, Sweden) bears a simple label reading "Ind." Forsberg (1821) apparently misinterpreted this to mean "Indies Oriental." Since the species occurs widely from Florida to Massachusetts and is not found in the East Indies, Indiana seems to be a likely type locality.

Gyretes compressus LeConte is another species, rare in collections, which is probably nocturnal in habits, withdrawing to heavily shaded or partially enclosed situations during the day. It was fairly common under the log mat in Owen County and also under banks of Richland Creek south of Bloomfield in Greene County (Young, 1978).

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ENVIRONMENTAL QUALITY

Chair: John Pichtel
Department of Natural Resources
Ball State University
Muncie, IN 47306

Chair-Elect: John Pichtel
Department of Natural Resources
Ball State University
Muncie, IN 47306

ABSTRACTS

Water Quality in the Calumet Aquifer in a Highly Industrialized Region of Indiana. Konrad J. Banaszak and Joseph M. Fenelon, U.S. Geological Survey, 5957 Lakeside Boulevard, Indianapolis, IN 46278.—Many sources of hazardous materials directly overlie the thin, water-table, low-hydraulic-gradient Calumet aquifer, whose water ultimately reaches Lake Michigan. Thirty-five stainless steel wells, including six pairs of nested wells, were sampled for 5 field characteristics and 112 laboratory constituents. Median pH was 7.3, but samples from three wells screened in slag had pH values above 11. Median specific conductance was 1,200 μS/cm (microsiemens per centimenter at 25 degrees Celsius), but six values exceeded 2,380 μS/cm. Of these six samples, three were from fresh slag and the other three were contaminated by petroleum products. Sixty-seven of the 88 organic chemicals analyzed for, including trichloroethylene, were not detected. Phenol, however, was found in samples from all 35 wells, and benzene was found in 17 of 35 samples. Medians of both chemicals in samples collected from wells in or near steel or petrochemical plants were significantly different (at the 95-percent confidence level) from medians in samples from all other wells.

The Effects of Zinc on Epilithic Communities in Artificial Streams. D. Dean-Ross, Indiana University-Purdue University at Fort Wayne, Fort Wayne, IN.—The effects of five concentrations of zinc on bacteria and algae colonizing surfaces in artificial streams were studied. Duplicate sets of streams received one of six treatments: no zinc supplement, 0.01, 01. 0.5, 1.0, or 10.0 ppm zinc. At weekly intervals surfaces were removed from the stream sand and assayed for total biomass, chlorophyll *a* content, total direct bacteria counts, total viable bacteria, and the abundance of resistant CFU. None of the measured parameters were significantly affected by 0.01 or 0.1 ppm zinc in comparison to the control. Zinc at a level of 0.5 ppm produced a 90% inhibition in total biomass and chlorophyll *a*, but only a 40% inhibition in total counts and viable CFU. Levels of 1.0 and 10.0 ppm zinc produced a 90% inhibition in all parameters. The bacterial community developed resistance to the concentration of zinc prevailing in the artificial streams, but were inhibited by concentrations in excess of the exposure concentration, with the exception of the community exposed to 1.0 ppm zinc, which demonstrated a tolerance to up to 10 ppm zinc. Zinc dependence developed in streams exposed to 0.5, 1.0, and 10.0 ppm zinc.

Evaporation of Liquid Chemical Spills: II. Computation of Downwind Concentrations and Plots of Evacuation Zones. Howard E. Dunn and Benjamin

P. MILLER, University of Southern Indiana, 8600 University Blvd., Evansville, IN 47712.—The atmospheric dispersion evaporative spill model we have developed can be used for doing risk assessments involving potential spills of toxic liquids. After inputting the name of the chemical, the length and width of the pool, the ambient temperature, the wind speed, and the weather stability class, the computer program can rapidly calculate the downwind concentration at selected points. There is provision for calculating concentrations at incremented distances, and for calculating and plotting evacuation zones. The plots can be drawn to an assigned scale on the computer monitor or produced by a plotter to the scale of a geological survey map. The isopleths can be drawn on a transparency which can be easily superimposed on a geological survey map at the site of the spill for the determination of the theatened area to be evacuated.

The Illinois-Indiana Sea Grant Program. BURNELL C. FISCHER, Department of Forestry and Natural Resources, Purdue University, West Lafayette, IN 47907.—The Illinois-Indiana Sea Grant Program has completed six years of operation. The program, which is the youngest of the nation's 31 Sea Grant Programs, is playing an ever increasing role in helping improve the environmental quality of Illinois-Indiana Lake Michigan shoreline through its research, extension, and communications programs. Our current activities center on environmental quality issues such as coastal recreation and tourism, high water levels and erosion problems, water quality, fisheries research, and marina development. In addition to program support for on-going staff efforts, we solicit research projects through a request for proposal process and provide quick response funds for preliminary research and special extension projects. The Illinois-Indiana Sea Grant Program is a joint effort between the University of Illinois at Champaign-Urbana and Purdue University at West Lafayette with principal funding support from the Office of Sea Grant, NOAA, U.S. Department of Commerce, Washington, D.C.

Mold Level Variation in the Air of Unoccupied Houses. C. GUINDON and T. GODISH, Indoor Air Quality Research Laboratory, Ball State University, Muncie, IN 47306.—Air samples for mold use were collected daily in an unoccupied stick-built house and a mobile home over periods of 9-12 months using a viable particle sampler. Total mold counts were reported as colony forming units/cubic meter (CFU/m^3). Significant differences in total mold counts were observed between the two structures. Significant day-day variations were also observed. The removal and reapplication of carpeting had a significant effect on mold levels in the mobile home. A significant increase in mold levels was observed when cabinetry which had been stored in a nonclimate-controlled space was introduced into the mobile home.

Microbial Respiration in Fly Ash-Amended Soil. JOHN R. PICHTEL, Department of Natural Resources, Ball State University, Muncie, IN 47306.—Coal fly ash, a by-product of the power generating industry, is produced in large quantities and requires land disposal. Little is known regarding its effects on the activity of the microbial population within soils. Acidic and alkaline fly ash were applied at 5, 10, and 20% (wt/wt) to two soils and incubated for 42 days. Microbial activity of the soils as indicated by CO_2 evolution was measured. The 10 and 20% ash treatments experienced a significant reduction in respiration, with reduction most pronounced using the alkaline ash. The pH and electrical conductivity of the treated soils were positively correlated with inhibition of respiration.

Scavenging of Urban Atmospheric Species by Dew. I. Within-Event Atmosphere and Dew Sampling Methodology. ROBERT A. PRIBUSH, JEFFREY R. FOSTER, BRADLEY H. CARTER, JENNIFER L. WAUGH, and COLLEEN O'DONNELL, Department of Chemistry and the Holcomb Research Institute, Butler University, Indianapolis, IN 46208.—While acid deposition has been widely studied in recent years, chemical inputs by dry deposition to ecosystems remains the least understood chemical deposition pathway. In this study, dew was used as a naturally occurring scavenging agent for gaseous and aerosol atmospheric species at the Butler University Environmental Preserve and a second sampling site near the center of Indianapolis. Since dew forms as pure water and then scavenges atmospheric species in its immediate vicinity on calm nights, the source of species found in dew is thought to be mainly local. Hence dew is an excellent medium for the study of local source-receptor relationships. Methodology used for sampling ambient atmospheric species and relating the concentrations of these species to dew species concentrations found in within-event studies is discussed. The use of dew in integrated monitoring-modeling studies to enhance the accuracy of estimated ambient chemical species concentrations and deposition rates in local assessment studies will also be demonstrated.

Scavenging of Urban Atmospheric Species by Dew. II. Results of Within-Event Atmosphere and Dew Sampling in an Urban Environment. ROBERT A. PRIBUSH, JEFFREY R. FOSTER, BRADLEY H. CARTER, JENNIFER L. WAUGH, and COLLEEN O'DONNELL, Department of Chemistry and the Holcomb Research Institute, Butler University, Indianapolis, IN 46208.—Ambient levels of SO_2, NO_2, HNO_3, O_3, NH_3, and particulates were sampled at intervals during the time of dew formation and compared to levels of corresponding species, SO_3^{2-}, SO_4^{2-}, NO_2^-, NO_3^-, and NH_4^+, found in dew collected sequentially during the same night at two urban sampling sites in Indianapolis. Other species (F^-, Cl^-, Na^+, K^+, Mg^{2+}, Ca^{2+}, and organic acids) in dew were also monitored in an attempt to better understand the chemistry involved at the dew-atmosphere interface and within the dew itself. Comparisons will be made with previous dew studies in Indianapolis, Warren, Michigan, Allegheny Mountain, Pennsylvania, and Claremont, California. As in earlier studies, the dew pH in Indianapolis had a neutral or slightly basic pH in contrast to acidic rains and fogs sampled at the same location. The dew chemistry was found to be dynamic throughout the night, suggesting the need for the development of a non-equilibrium model to explain the scavenging of atmospheric species by dew.

Studies on the Phototoxicity of Hydrocarbon Fractions in Grand Calumet River Sediments. ANNE SPACIE, Dept. of Forestry and Natural Resources, Purdue University, W. Lafayette, IN 47907 and Richard Davenport, School of Life Science, University of Illinois, Urbana, IL 61801.—The Grand Calumet River in northwest Indiana receives large inputs of hydrocarbon pollutants derived from petroleum, steel-making, and other industrial and urban activities. Several polyaromatic hydrocarbons from such sources are known to bioaccumulate in aquatic organisms and to be carcinogenic to fish. Much less recognized is the potential for photo-induced toxicity of these same hydrocarbons. Sediments from the Grand Calumet have been collected, extracted, and tested in bioassays designed to assess phototoxicity and photomutagenicity in aquatic organisms. Sediment elutriates from some collection sites were significantly more toxic following exposure to UV light or natural sunlight. Several methods to characterize the complex organic fractions and to relate toxicity to specific fractions have been tested. Based on this research, it appears that dredging or other disturbance of river and harbor sediments could lead to important releases of phototoxic hydrocarbons.

A Survey for Organochlorine Chemicals, Polynuclear Aromatic Hydrocarbons, and Inorganic Compounds in Biota near a Landfill in Fulton County, Indiana. DONALD W. STEFFECK, U.S. Fish & Wildlife Service, 718 North Walnut Street, Bloomington, IN 47401.—The Four County Landfill is a 61.5 acre hazardous waste landfill that has been in operation since the early 1970's. Numerous complaints and alleged violations at Four County Landfill have been made by local citizens and State and Federal Agencies. The landfill has numerous wetlands and associated fish and wildlife resources nearby, including King Lake and the Tippecanoe River. In the spring and summer of 1987, the U.S. Fish & Wildlife Service collected several varieties of aquatic and terrestrial biota from areas suspected of receiving runoff from Four County Landfill. These organisms were analyzed for organochlorine pesticides including total PCB's, polynuclear aromatic hydrocarbons, and 14 inorganic compounds. Organic contaminants were not found in most biota near the landfill. Several inorganic compounds were found to be prevalant over background levels including manganese, aluminum, zinc, cadmium, mercury, and nickel. These compounds are present in waste disposed at Four County Landfill and have been documented at elevated levels in the groundwater and surface water near the site. The maximum concentrations found in the biota are at levels considered elevated, and at least cautionary for consumption by predators.

Geohydrology of the Calumet Aquifer, Northwestern Indiana. LEE R. WATSON and JOSEPH M. FENELON, U.S. Geological Survey, 5957 Lakeside Boulevard, Indianapolis, IN 46278.—The Calumet aquifer underlies a highly industrialized region of northwestern Indiana. This water-table aquifer is composed of fine to medium beach and dune sand less than 65 feet thick. The water table generally is less than 8 feet below land surface. The geohydrologic characteristics of the Calumet aquifer were defined so that a network of ground-water observation wells could be properly installed for a subsequent water-quality study. Maps of the water table and aquifer geometry were prepared, aquifer/stream interactions were monitored, and finite-difference digital models were constructed. The water table has broad, low-gradient mounds that generally lie between the major surface-water drains. Aquifer/stream interactions are complex and are dependent on the stage of Lake Michigan. In the 70-square-mile modeled area, the aquifer discharges about 5 to 10 feet^3/s (cubic feet per second) of water to the Grand Calumet River/Indiana Harbor Canal, which subsequently drains to Lake Michigan. Less than 5 ft^3/s of water discharges directly to Lake Michigan along 20 miles of shoreline. In addition, 20 to 25 ft^3/s of ground-water discharges to leaky sewer systems.

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RECENT WATER QUALITY IN THE GRAND CALUMET RIVER AS MEASURED BY BENTHIC INVERTEBRATES

Greg R. Bright
Commonwealth Biomonitoring
7256 Company Drive
Indianapolis, Indiana 46237

INTRODUCTION

The Grand Calumet River system in northwestern Indiana flows through one of the most highly industrialized areas of the country. Most of the flow in the river is composed of industrial and municipal wastewater, and water quality has been severely degraded for many years. Low dissolved oxygen and high ammonia, phenol, cyanide, metal, polycyclic aromatic hydrocarbon (PAH's), polychlorinated biphenyl (PCB's), and volatile organic compound (VOC's) concentrations have been detected in water and/or sediments in the river (Hydroqual, 1984). This study was undertaken to measure the biological effect of this degradation, to help identify particular water quality problems, and to provide baseline data to document any changes that may occur in the future. Monitoring benthic invertebrates proved useful in this study, because these animals are relatively immobile and, therefore, sensitive to local conditions.

METHODS

During the summers of 1986-1988, macroinvertebrates were collected on Hester-Dendy artificial substrate samplers (Fullner, 1971) suspended from bridges or other stationary objects at six sites in the Grand Calumet River system (Figure 1). Two or three samplers were set approximately one meter below the surface in the area of most rapid current velocity (0 to 30 cm/sec) at each site. Most samplers were set in mid-June or early July and retrieved 5 to 8 weeks later, although the 1987 samplers had an 18 week exposure period. Crayfish were also collected at each site in basket traps baited with meat. The basket traps were set in June or July each year, left overnight at each site, and checked the next day for captured animals. All macroinvertebrate samples were preserved in the field and sorted, identified, and enumerated in the laboratory. Everything was identified to the genus or species level, except the oligochaetes, which were identified only to order.

Several biometrics commonly used to assess water quality were applied to the data (EPA, 1983). The number of genera observed in a sample (generic richness) was calculated by treating oligochaetes as a single genus and omitting genera represented by only one individual. Percent similarity to a reference site (see below) was measured with a Jaccard Similarity Coefficient, using the taxonomic order level to compare similarity between sites. The Shannon-Weaver Diversity Index was also calculated using order level identifications at each site. Dominant genera, as discussed in the text, included those groups which constituted at least 25% of all individuals in a sample.

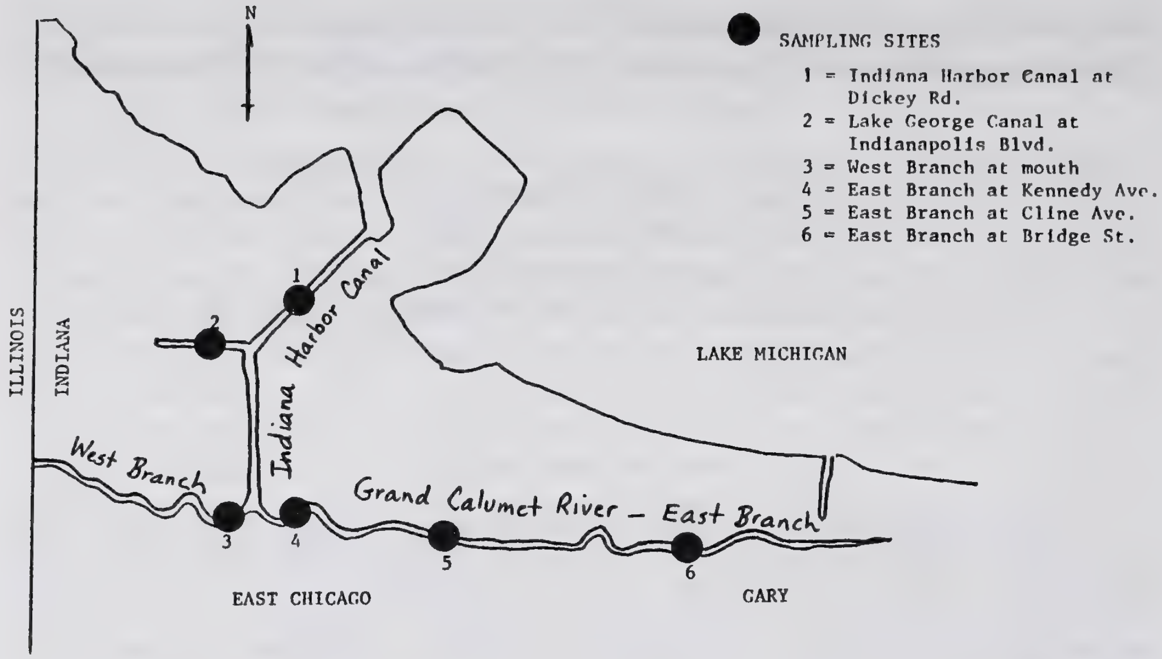
N
SAMPLING SITES
1 = Indiana Harbor Canal at Dickey Rd.
2 = Lake George Canal at Indianapolis Blvd.
3 = West Branch at mouth
4 = East Branch at Kennedy Ave.
5 = East Branch at Cline Ave.
6 = East Branch at Bridge St.
LAKE MICHIGAN
ILLINOIS
INDIANA
Indiana Harbor Canal
West Branch
Grand Calumet River – East Branch
1
2
3
4
5
6
EAST CHICAGO
GARY

FIGURE 1. Location of macroinvertebrate sampling sites within the Grand Calumet River Basin.

RESULTS AND DISCUSSION

The macroinvertebrate groups present at the six sampling sites are summarized in Table 1. Five main groups of macroinvertebrates were present at every site. The most obvious common characteristic of this assembledge is the tolerance of each group to moderate organic pollution, especially reduced dissolved oxygen concentrations. No "intolerant" species were present at any of the sites. However, the presence of many "facultative" organisms (especially odonates and certain midges and snails) indicates that severe oxygen depletions do not occur.

The benthic fauna at all six sites also appeared to be stressed by toxic chemicals. In every sample, *Cricotopus bicinctus* and/or *Parachironomus abortivus* were the dominant midge larvae, both of which are found most abundantly in waters affected by toxic wastes (Simpson and Bode, 1980). Also, each of the samples was missing important faunal elements occurring in similar but unstressed habitats. For example, artificial substrate samples from Burns Ditch, a similar habitat about 30 kilometers east of the Grand Calumet River, regularly included amphipods, caddisflies (Psychomiidae), bryozoans, and several genera of heavy-bodied midge larvae in the subfamily Chironomini (IDEM, unpublished data). These groups are generally tolerant of mild organic population but can be quite sensitive to certain toxic chemicals (Hart and Fuller, 1974; Mayer and Ellersieck, 1986). All were rare or absent in the Grand Calumet River samples.

Table 1 also shows the results of several common biometrics used to assess water quality at each of the six Grand Calumet River sites as well as at a reference site (Burns Ditch). Taxa richness, percent similarity to the reference station, and the diversity index all generally increase as water quality improves (EPA, 1983). According to Table 1, the most biologically stressed site in the Grand Calumet River was at Bridge Street, immediately downstream from the outfalls of a large steel mill and several combined sewer overflows from the City of Gary. This site had lower taxa richness, lower diversity, less similarity to the reference site, and was often dominated by the toxics-tolerant midge, *Cricotopus bicinctus*.

TABLE 1. Average of all samples during the study period. Numbers beside each macroinvertebrate group are proportions of that group in the total sample (+ = < 1% of total sample; Gam = *Gammarus*; Dicro = *Dicrotendipes*; Crico = *Cricotopus*; oligo = oligochaetes; bryo = bryozoa).

	Reference	**Bridge**	**Cline**	**Kennedy**	**Branch West**	**IHC**	**Lake George Canal**
Oligochaetes	+	.21	.25	.47	.66	.92	.38
Leeches	+	.02	.04	.28	.05	.01	.04
Snails	.13	.51	.20	.04	.08	.03	.40
Midges	.52	.24	.49	.20	.18	.03	.10
Odonates	.05	.02	.02	.01	.03	.01	.08
Others	.30	+	+	+	+	+	+
Generic Richness	18	7	9	9	8	8	12
Percent Similarity to Reference	100	39	52	45	55	55	52
Diversity Index	1.25	1.14	1.22	1.22	1.02	0.39	1.30
Dominant Genera	Gam Dicro	Physa Crico	Crico oligo	oligo	oligo	oligo bryo	oligo bryo Physa

TABLE 2. Biometrics applied to Indiana Harbor Canal samples, 1979-1988 (oligo = oligochaetes and bryo = bryozoa).

	Year							
	79	**80**	**81**	**82**	**84**	**86**	**87**	**88**
Generic Richness	1	5	1	6	6	9	8	7
Percent Similarity to Reference	9	36	9	55	55	64	45	45
Diversity Index	0	0.04	0	0.06	0.06	1.08	0.24	0.20
Dominant Taxa	oligo	oligo	oligo	oligo	oligo bryo	sponge bryo	oligo	oligo

By evaluating the environmental requirements and sensitivities of the species present, it is possible to narrow the range of chemicals responsible for toxic-related stress. For example, most metals can be ruled out as a primary cause of stress in the system because the snail, *Physa,* which is quite sensitive to many metals (Nebeker, 1986), was present and sometimes dominant at all sites. In addition, no metals in potentially toxic concentrations have been detected in any recent water samples from the Grand Calumet River and Indiana Harbor Canal (Indiana Department of Environmental Management, 1985). PCB-related stress was also not evident from these results. Crayfish *(Procambarus acutus* and/or *Cambarus diogenes)* appeared to be equally abundant at most sites, including Bridge Street, where the highest PCB concentrations in sediments were located (Hydroqual, 1984). Although the amount of available toxicity data is limited, crayfish seem to be at least as sensitive as most other organisms tested for PCB toxicity (EPA, 1980a).

There is some evidence that cyanide and/or PAH's may be responsible for the toxic-related stress observed in the Grand Calumet River system. Sediment concentrations of both these chemical groups were highest at Bridge Street (Hydroqual, 1984), which was also the most biologically depressed site. The absence of amphipods from a habitat where they should be numerically dominant could be at least partially attributed to cyanide toxicity, since amphipods are among the most cyanide-sensitive invertebrates known (EPA, 1984). They are also taxonomically and ecologically similar to mysid shrimp, which are the most PAH-sensitive organism tested to date (EPA, 1980b).

Table 2 summarizes recent annual changes that have occurred in the benthic fauna of the Indiana Harbor Canal and includes previously unpublished data collected by the Indiana Department of Evironmental Management from the site between 1979 and 1984. All of the biometrics applied to this data indicate that water quality in the Canal was highest in 1986 and has declined somewhat since then. Water levels in Lake Michigan reached historic highs in 1986 (Indiana Department of Natural Resources, 1986), and the improved benthic fauna that year may have been caused more by lake water dilution than by wastewater treatment improvements in the basin. Nevertheless, recent water quality in the Canal, as measured by benthic invertebrate community structure, has improved markedly since 1979.

SUMMARY

Benthic invertebrates were collected on artificial substrate samplers from the Grand Calumet River system during the summers of 1986-88 to determine recent water quality. The benthic communities observed each year indicated stress from both low dissolved oxygen and toxic substances. Although the sediments are highly contaminated with metals, stress from metals toxicity was not apparent in this study. Toxicity from cyanides and/or polycyclic aromatic hydrocarbons is more likely. The most biologically depressed site was at Bridge Street in Gary. This site receives wastewater from a large steel mill as well as several combined sewer overflows and has the most highly contaminated sediments for most chemical parameters. Overall, the benthic community appeared least stressed in 1986, when Lake Michigan water levels were at historic highs. Similar studies done since 1979 show that water quality in the Grant Calumet River system has improved markedly since that time.

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A COMPUTER MODEL FOR THE ATMOSPHERIC DISPERSION OF TOXIC VAPORS RESULTING FROM LIQUID CHEMICAL SPILLS

Benjamin P. Miller and Howard E. Dunn
School of Science and Engineering Technology
University of Southern Indiana
Evansville, Indiana 47712

INTRODUCTION

In two previous papers, the authors presented results from computer models for downwind concentrations of toxic gases, resulting from continuous sources and from instantaneous releases (Dunn and Miller, 1979, 1981). A third case involving atmospheric dispersion of toxic gases can arise from the accidental spilling of a volatile liquid chemical and subsequent evaporation.

Chemical spills are an unavoidable risk in modern life. A popular news magazine (Huntley, 1983) reported an estimated 180 million shipments in the United States of explosive, corrosive, flammable, poisonous, or radioactive materials by highway, rail, water, and air each year. An atomospheric dispersion model for an evaporative spill is presented in this paper as well as the results obtained from a computer program developed for its application. This computer program should be very useful to local emergency planning committees formed as a result of the Emergency Planning and Community Right-to-Know Act of 1986. The program allows for a sophisticated and thorough analysis of problems arising from the accidental spillage of toxic liquids.

DEVELOPMENT OF THE MODEL

The basic equation for downwind concentrations of toxic gases resulting from the evaporation of a liquid pool was obtained by considering the pool as a continuous source with zero plume height. This adaptation was applied to a standard model equation given for the prediction of downwind concentrations from a continuous source (Turner, 1970). The equation was further modified by doubling the concentration magnitude to allow for reflection by the ground surface. The resulting model equation is:

$$C = (2Q/\sigma_y\sigma_zU\pi)\mathrm{Exp}[-.5(Y/\sigma_y)^2],$$

where C (g/m^3) is the atmospheric concentration predicted for the specified position, Q (g/s) is the emission rate or source strength from evaporation of the toxic chemical from the pool, σ_y (m) and σ_z (m) are the horizontal and vertical atmospheric dispersion coefficients, U (m/s) is the wind speed, and Y (m) is the lateral displacement from the centerline determined by the wind direction from the pool.

Data for the atmospheric dispersion coefficients are reported in the form of curve plots against downwind distance in families over the six weather stability categories (Turner, 1970). These plots are on logarithmic scales varying over several orders of magnitude. Previously reported studies used functional approximations for these plots using logarithmic functions (Dunn and Miller, 1979, 1980). However, improved functional approximations using the exponential form ($\sigma = ax^b + c$) to represent both σ_y and σ_z for x the downwind distance were developed for this project resulting in a simpler calculation that produced more uniformly accurate approximations. A relation was derived for the determination of the exponent b for three data points read from the curve plots. For σ_1, σ_2, σ_3 obtained at distances x_1, x_2, x_3 related by $x_2 = kx_1$, $x_3 = kx_2 = k^2x_1$, with k a numerical factor such as 4 or 10, it follows $\sigma_1 = ax_1^b + c$, $\sigma_2 = ak^bx_1^b + c$, $\sigma_3 = ak^{2b}x_1^b + c$ and $b = \log R_s/\log k$ for $R_s = (\sigma_3 - \sigma_2)/(\sigma_2 - \sigma_1)$. In some cases, solutions were obtained from several data sets and averaged. For σ_{z},, the distance range of $1\text{x } 10^2$ to 10^5 m was divided into two subranges and separate solutions obtained on each. The final solution for the constants a and c were obtained by a modified linear regression which was derived to minimize the sum $\Sigma_j[1 - (ay_j/\sigma_j) - (c/\sigma_j)]^2$, for $y_j = (x_j)^b$, σ_j and x_j representing points taken from the curve plots. In this form the squared fractional or percent variations are minimized as suitable for data varying by orders of magnitude, rather than the more common squared magnitude variations, so that large and small values of the σ_j's carry equal weight. Values computed from the functional approximations were found to agree in all cases to within five percent of values read from the curve plots.

Two literature reports were located which presented empirically established methods for the computation of evaporation rates from liquid pools exposed to wind currents (Clewell, 1983; Wade, 1942). Results from the two methods were found to differ appreciably but agree in order of magnitude. The evaporation rate given by Clewell (1983) with converted units is expressed as:

$$R = 2.222\text{x}10^{-6}U^{.75}(1 + 4.3\text{x}10^{-3}T^2)Z,$$

where R (g/cm²•s the evaporation rate, U (m/s) is the wind speed T (°C) is the pool temperature, and the factor Z is calculated as $Z = P_vM/(P_HM_H)$, for P_v (mm Hg) and M, the vapor pressure and molecular mass of the specified chemical, respectively, and P_H and M_H, the vapor pressure and molecular mass of hydrazine, respectively. The evaporation rate given by Wade (1942) with converted units is expressed as:

$$R = 1.975\text{x}10^{-9}\ M^{.71}\ P_vU^{.85},$$

with R, M, and P_v as before and U (cm/s).

One set of experimentally measured values of evaporation rates of toluene at 20° C (68° F) at varying wind speeds had previously been obtained from a wind tunnel apparatus by a research student, Gary Lutz, at the University of Southern Indiana (Dunn, *et al.*, 1985). The wind tunnel apparatus, designed by the authors and constructed and donated by George Koch Sons Inc., was described in a paper presented by Charles Macer (Dunn, *et al.*, 1984). A comparison of results of both computations with these experimental results are given in Table 1, and it is seen that all agree in order of magnitude. Both the calculations of Wade (1942) and Clewell (1983) are employed in the model, with the larger value of the two selected for the atmospheric dispersion calculations. Since these calculations have rela-

TABLE 1. Comparison of computed and measured evaporation rates for toluene at 20°C (68°F) at various wind speeds. Rates are expressed as (g/cm²s) x 10^4.

Wind Speed (mi/hr)	Computed Rate (Clewell)	Computed Rate (Wade)	Measured Rate (Lutz)
15.9	1.77	2.84	3.79
12.0	1.44	2.24	2.94
7.8	1.04	1.55	2.67
4.9	.73	1.04	2.00

tively high uncertainty, the worst case is selected to provide a factor of safety. The pool temperature is estimated as the ambient air temperature. The vapor pressure is calculated in the model for various chemicals from empirical formulas given in Lange's handbook (Dean, 1973). The emission rate to be used in the atmospheric dispersion model is calculated as the product of the evaporation rate and an estimated area of the pool.

The application of the model to the calculation of isopleths, curves of constant atmospheric concentration, is based on solving the previous atmospheric dispersion equation for the lateral displacement Y (m) at which a specified concentration occurs. The resulting equation is expressed as:

$$Y = \sigma_y[2 \text{ Ln } (2Q/\sigma_y\sigma_z U\pi C)]^{.5},$$

in which Ln designates the natural logarithmic function and all the other symbols have the same meaning as before.

A computer program was written to carry out the computations of the model with various options. Provisions were made for entering the necessary parameters in common English units and converting them within the program to the metric units used in the calculations. The program initially reads in a data file containing the required data for specific chemicals. The data file contains the chemical name, the parameters required for the calculation of its vapor pressure as a function of temperature, the molecular mass, and the threshold limit value of concentration for safe exposure for each chemical. The file is in alphabetical order by the chemical name, so that after it is read into the computational program, the specific chemical can be searched out by name. An auxiliary program was written for preparation and augmentation of this data file. New chemicals and their data can be added to a previously prepared file and the file automatically realphabetized.

APPLICATION OF THE MODEL

The evaporative spill computer model was written in BASIC for use on an IBM-PC equipped with a color graphics monitor. To use the full capabilities of the program, a printer and a Hewlett Packard model 7475A plotter are needed.

The person at the scene of the toxic liquid spill must input the name of the chemical, the estimated length and width of a rectangle that would encompass the pool, the ambient temperature, the wind speed, and the weather stability class. Once this information has been entered, the program responds with a menu listing the following three options: 1) downwind concentration at selected points;

TABLE 2. Downwind concentrations along the center line for an evaporative spill of benzene. Pool size 10 feet by 15 feet. Ambient temperature 80° F. Wind speed 5 mi/hr. Weather stability class D.

Downwind Distance (miles)	Concentration (mg/m^3)	Concentration (ppm)
0.2	57.15	18.00
0.4	17.22	5.42
0.6	8.61	2.71
0.8	5.55	1.75
1.0	3.87	1.22
1.2	2.90	.91
1.4	2.28	.72
1.6	1.86	.59

2) downwind concentrations over incremented intervals; and 3) isopleth calculations with plot and display options.

Downwind concentrations at selected points. This option allows the rapid determination of the concentration of the vapors at any point downwind from the chemical spill. The point can be selected at any downwind distance either on or off the center line of the plume. This option would be useful if you knew of a sensitive area, for example, a school of a nursing home, at a given distance downwind from the spill, and you needed to make a rapid determination of whether or not a hazardous concentration of vapors might exist at that point.

Downwind concentration over incremented intervals. This menu selection allows the calculation of the downwind concentration of the vapors along the centerline at incremented downwind distances (Table 2). It also allows the computation of concentrations at downwind distances at a constant lateral distance from the center line. In addition, certain provisions allow the calculation of concentrations at incremented distances across the plume at a constant downwind distance.

The first two provisions in the program are useful in rapidly determining how far downwind a dangerous concentration of vapors would be expected. These values could be used to start an evacuation before the more precise evacuation area could be determined.

Isopleth calcualtions with plot and display options. Perhaps, the most useful aspect of the program is its capability to display evacuation zones on the screen or plot them on a graph. The screen option displays the evacuation zone on the computer monitor to an assigned scale. The plot command has two options: 1) plot to an assigned scale; or 2) plot to map coordinate scale (transverse Mercator). Option 1 allows you to plot an isopleth at a selected concentration. For example, if you selected 1 mg/m^3, the program would draw an enclosed figure representing an evacuation zone as the total area encompassed by the 1 mg/m^3 isopleth. The plot would be drawn to any mapping scale that you select. Option 2 represents the most easily used plotting option. This option plots the evacuation zone to the scale of a geological survey map (Figure 1). The plot of the evacuation zone can be made on a transparency. The origin of the spill on the transparency

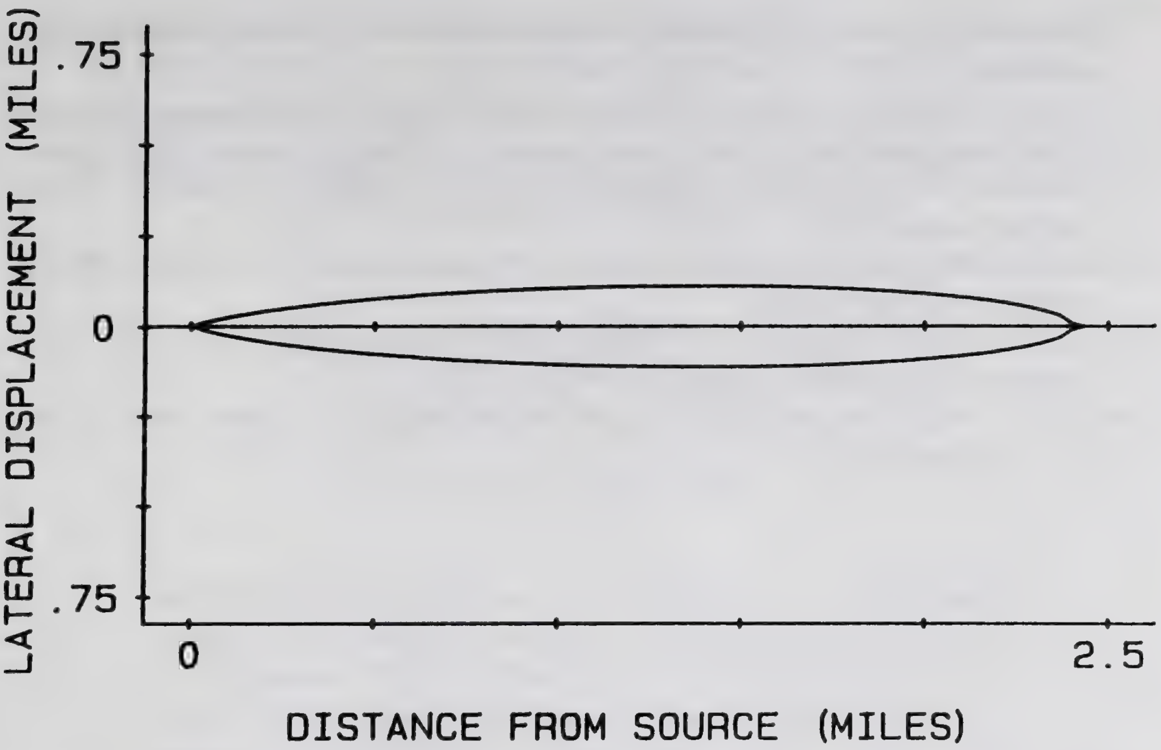

FIGURE 1. Isopleth for an evaporative spill of benzene. Pool size 10 feet by 15 feet. Ambient temperature 80° F. Wind speed 5 mi/hr. Weather stability class D. Isopleth concentration 1 mg/m^3.

can be superimposed over the spill location on the geological survey map and the centerline on the transparency oriented to the downwind direction. The area for evacuation is immediately apparent.

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SUB-CHRONIC TOXICITY EVALUATION OF MAJOR POINT SOURCE DISCHARGERS IN THE GRAND CALUMET RIVER AND INDIANA HARBOR CANAL, INDIANA, USING THE EMBRYO-LARVAL SURVIVAL AND TERATOGENICITY TEST

Thomas P. Simon
U.S. Environmental Protection Agency
Central Regional Laboratory
536 S. Clark Street
Chicago, Illinois 60605

ABSTRACT: Preliminary and definitive use of sub-chronic embryo-larval toxicity testing was conducted to interpret the specific impact of 19 point source dischargers along the Grand Calumet River and Indiana Harbor Canal. Preliminary screens were utilized to evaluate potential effects in 100% effluent, when compared to the control. Hammond SD had a significant teratogenic response during the preliminary test but did not exhibit a reduction in larval survival. Six positive results were obtained and retested as definitive tests. USX company was unavailable for definitive testing due to plant shutdown. East Chicago Sanitary District did not elicite a chronic response during definitive testing. However, statistically significant teratogenic responses were observed in larvae in all dilutions tested. Inland Steel outfalls 008 and 014 had chronic values of 77.5% and 42.4% effluent, respectively. Only Inland Steel outfall 014 had a statistically significant teratogenic response, affecting larvae in all dilutions tested. E.I. DuPont de Nemours and Company within 168 hrs of exposure, concentrations above 30% effluent had significant morality. A chronic value of 17.3% effluent was calculated for DuPont and statistically significant teratogenic responses were observed in dilutions above 30% effluent. Hatchability was unaffected in all preliminary tests except USX outfall 034. Statistically significant differences in definitive test hatchability were observed in 100% Inland Steel outfalls 008 and 014.

INTRODUCTION

Water quality in the Calumet region of northwest Indiana and northeast Illinois has been a matter of public concern for more than a decade (U.S. Department of the Interior, 1966, 1967; U.S. Environmental Protection Agency, 1982). The watershed is heavily urbanized, with the principal cities of Gary, Hammond, East Chicago, and Whiting collectively supporting populations over 500,000. The basin also includes one of the most concentrated steel and petrochemical industrial complexes in the United States.

TABLE 1. Summary of test procedures utilized for embryo-larval survival and teratogenicity testing of Grand Calumet River Basin.

Test type	Static Renewal
Temperature	26° ± 1° C
Light quality	Ambient environmental chamber
Light intensity	50-100 ft-c
Photoperiod	16 hrs light, 8 hrs dark
Test chamber size	600 mL
Test solution volume	400 mL
Renewal of test solutions	Every 24 hrs
Age of test organisms	Less than 48 hrs old embryos
Number of embryos/chamber	50
Number of replicate test chambers per concentration	2
Embryos/concentration	100
Feeding regime	Feeding not required
Aeration	None, unless dissolved oxygen is below 40% saturation
Dilution water	Dechlorinated micro-filtered tapwater
Test concentrations	0, 3, 10, 30, 60, 100% effluent
Dilution	0.3
Test duration	192 hrs (8 days)
Measurement end-points	Percent hatchability; percent larval survival; relative percent teratogenicity of live and dead organisms

Alarm over the poor water quality in streams draining this region into southern Lake Michigan initiated the formation of the Calumet Area Water Quality Committee in the late 1960's under the auspices of the Federal Water Pollution Control Administration (FWPCA). A series of meetings and symposia were initiated to assess the effectiveness of on-going pollution control programs and the relative progress toward meeting water quality objectives. The Technical Committee on Water Quality (1970) concluded that no significant improvement in water quality had been realized over the 1965 baseline condition despite discharger compliance with then-existing water quality criteria and requirements. With the replacement of the FWPCA by the U.S. Environmental Protection Agency (USEPA), a nationwide intiative was instituted. Emphasis shifted from the site specific implementation of the Calumet Area Water Quality Committee to a broad based USEPA water pollution control program, which incorporated many of the previous recommendations.

The basin's poor water quality and potential effects on the adjacent nearshore area of Lake Michigan prompted the drafting of a master plan for the Grand Calumet River (U.S. Environmental Protection Agency, 1985) to identify or develop required remedial actions, additional pollution control needs, and an implementation schedule and plan. The USEPA has identified a series of objectives and goals within the context of the master plan to improve water quality within the Grand Calumet River. Through the National Pollution Discharge Elimination System (NPDES) permit program, more stringent effluent limitations may be

TABLE 2. Chemical and physical properties of nineteen point source dischargers in the Grand Calumet River Basin during July and August 1986.

Outfall	pH	Hardness (mg/L CaCO^3)	Alkalinity (mg/L CaCO^3)	Specific Conductance (μS)
East Chicago	7.78	247-259	149-160	1464
East Chicago[a]	8.10	133-138	253-265	1575
Gary STP	8.10	227-255	149-159	728
Hammond STP	7.90	200-256	235-249	1119
U.S. X				
002	8.22	115-147	112-154	279
007	8.32	128-142	112-126	278
010	7.81	137-145	112-124	378
018	8.04	117-143	100-106	252
020	7.39	125-142	100-120	282
030	8.29	132-147	113-126	330
034	7.80	211-224	98-109	535
E.I. DuPont de Nemours				
003	7.42	510-540	30-40	8670
003[a]	7.22	392-400	24-30	8480
LTV Steel				
009	8.05	133-150	101-109	355
010	7.98	154-175	110-124	434
011	8.39	116-139	60-64	441
Inland Steel Co				
002	8.17	90-147	96-117	286
008	8.10	104-138	104-119	301
008[a]	8.24	101-108	138-145	339
011	8.66	117-156	105-129	300
012	8.30	131-142	103-114	329
014	8.26	151-189	88-103	458
014[a]	7.87	148-164	88-96	467

[a] Water chemistry for definitive sample.

instituted to minimize the introduction of toxic pollutants currently entering the river. USEPA is focusing attention on improving the immediate river channel. The current study assesses the sub-chronic toxicity of 19 major point source dischargers along the Grand Calumet River and Indiana Harbor Canal, using the embryo-larval survival and teratogenicity test.

MATERIALS AND METHODS

All tests of industrial and municipal effluents were conducted under similar conditions by personnel of the USEPA, Central Regional Laboratory in Chicago,

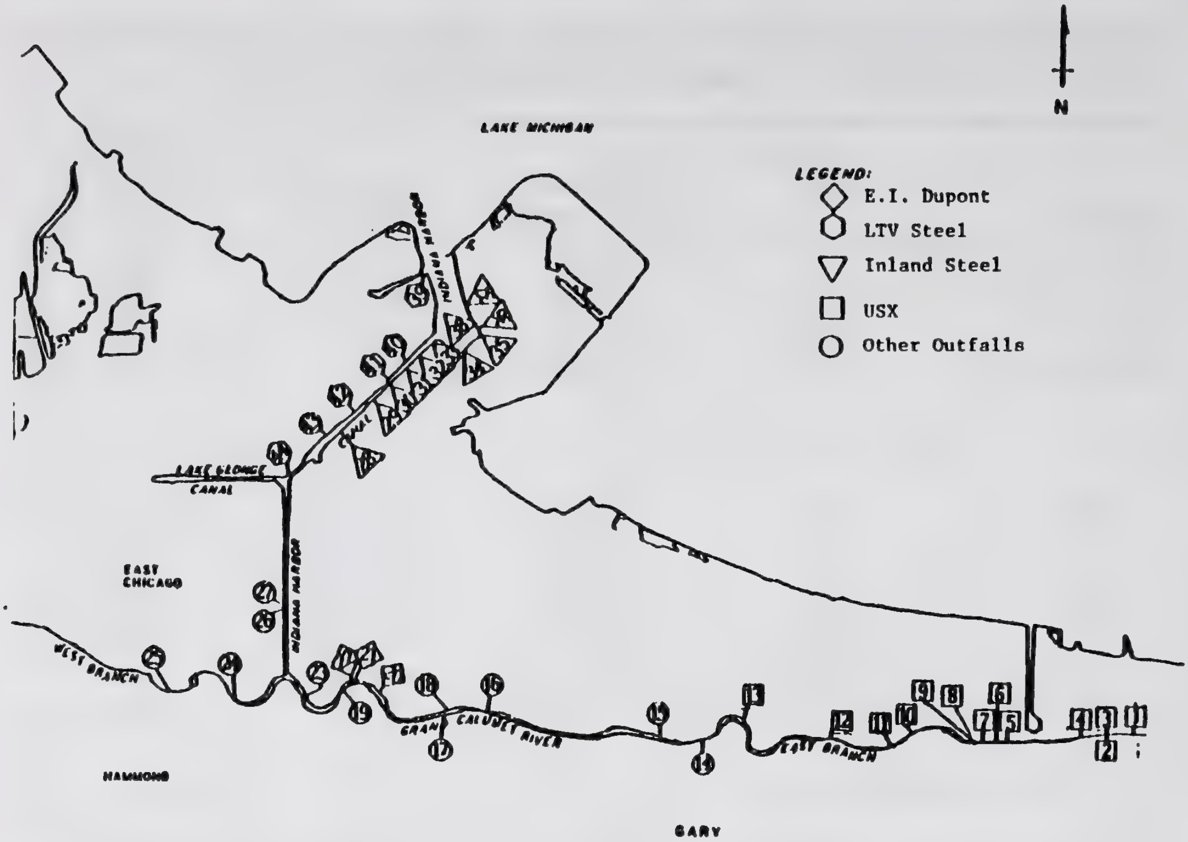

FIGURE 1. Point source dischargers in the Grand Calumet River basin, Indiana (Modified from ISBH, 1984).

Illinois. The tests were conducted within 24 hrs of sample collection as static, 8-day, daily renewal tests in a walk-in environmental chamber capable of regulating temperature, humidity, and photoperiod. Water temperatures were sustained within ± 1° C of 24° C. Photoperiod was set at 16 hrs light and 8 hrs dark. Standard culture methods and techniques were employed by personnel of the USEPA, Environmental Support Laboratory, Biological Methods Branch, Aquatic Biology Section, Newtown, Cincinnati, Ohio, following methods outlined in Klemm (1985). Fathead minnow *(Pimephales promelas)* eggs from the prior 24 hrs spawn were collected from spawning tiles at Newtown and shipped express mail in styrofoam containers to Chicago. Eggs were all spawned over an 8 hr period and were less than 48 hrs old at the initiation of each test.

The specific methods of the test follow Horning and Weber (1985) and were adapted from Birge and Black (1981) and Birge, *et al.* (1985) with a few modifications documented in *Standard Operating Procedures for Conducting Chronic, Static Embryo-Larval Survival and Teratogenicity Testing of Effluents* (U.S. Environmental Protection Agency, 1986). A summary of the test methods is presented in Table 1. Modifications to the test procedure include: lowering the volume of test solution to 400 ml; use of an egg cup with nitex mesh screening to facilitate egg and larvae manipulation during the test; sample collected as a single grab sample refrigerated at 4° C for the duration of the eight days; and deletion of teratogen-affected larvae (which were alive at the conclusion of the test) from the dead category for the derivation of the chronic value.

The deletion of abnormal fathead minnow larvae from the calculation of the chronic value removed any subjective bias on the part of the analyst in distin-

TABLE 3. Preliminary test results for municipal and industrial dischargers in the Grand Calumet River Basin during July and August 1986.

Effluent Concentration	Percent Hatchability	Relative Percent Teratogenicity			Percent Survival		
		Alive	Dead	Total	A	B	x̄
Control[a]	97	0	0	0	94	88	91
Hammond STP (100%)	97	0	7.2	7.2	80	96	88
Gary STP	95	0	1.0	1.0	84	94	89
East Chicago	99	7.1	26.3	33.3	2	46	24*
DuPont de Nemours							
003	100	—	—	—	0	0	0*
USX							
002	99	0	0	0	100	92	96
007	97	0	0	0	92	86	89
010	97	56.7	0	56.7*	0	0	0*
018	91	0	0	0	86	98	92
020	98	0	0	0	94	—	94
030	98	1.0	0	1.0	90	84	87
034	80*	0	0	0	7	6	6.5*
Control[b]	100	0	1	1	100	98	99
LTV Steel							
009	98	0	0	0	98	88	93
010	99	0	0	0	88	96	92
011	94	1.1	0	1.1	94	82	88
Inland Steel							
022	100	2.0	0	2.0	92	92	92
008	100	0	0	0	88	88	88*
011	96	0	0	0	90	92	91
012	100	0	2.0	2.0	90	94	92
014	99	0	2.0	2.0	88	72	80*

* Signifies a significant deviation between the control and test concentration using Students t-test ($P \leqslant 0.05$)

[a] Control sample for Hammond STP, Gary STP, East Chicago SD, DuPont de Nemours, and USX outfalls.

[b] Control sample for LTV Steel and Inland Steel outfalls.

guishing the severity of teratogenicity. The expression of teratogenicity is dependent on the age of the egg, since differences in exposure periods (e.g., exposure during cleavage) may significantly enhance or reduce the teratogenic response. To ensure that all eggs were affected by the effluent and did not die due to lack of fertilization, only embryos ranging between 48 to 72 hrs old at the initiation of the test were used. This enabled the analyst to distinguish between fertile and nonfertile eggs prior to placement into the test dilution series. A decreasing di-

TABLE 4. Definitive test results of municipal dischargers exhibiting preliminary screen chronic toxicity, teratogenicity, or hatchability deviations from the control.

Effluent Concentration	Percent Hatchability	Relative Percent Teratogenicity Alive	Dead	Total	Percent Survival A	B	x̄
East Chicago STP							
0	96	0	0	0	96	98	97
3	98	4.2	1.0	5.2*	84	96	90
10	98	2.0	1.0	1.3*	98	90	94
30	98	0	1.0	1.0*	100	92	96
60	98	1.0	3.0	4.0*	84	100	92
100	94	7.4	30.9	38.3*	92	68	80

* Signifies a significant deviation from the control using Student t-test.

lution series comprised of five effluent concentrations (3%, 10%, 30%, 60%, and 100%) was used for definitive testing. Control and dilution water was charcoal-filtered Lake Michigan water from the USEPA, Central Regional Laboratory—Fish Culture Unit, which was filtered through a 0.22 μm filter to remove any deleterious microorganisms.

During the course of preliminary screening, effluent at three test sites was routinely monitored to ensure sample integrity. The following parameters were monitored: ammonia, hardness, alkalinity, pH, and specific conductivity. No significant deviation was observed over the eight-day period of any parameter during the testing period for East Chicago Sanitary District, Gary Public Owned Treatment Works, and USX outfall 010. The decision was made that a single sample could be utilized in the daily renewal process for the duration of the test.

The endpoints evaluated in the study were the following: survival, hatchability, and relative percent teratogenicity. Routine monitoring of the physical properties of the test solution and their control on a daily basis included: temperature, dissolved oxygen, specific conductance, pH, alkalinity, and hardness (Table 2). Since many tests were conducted over a short time span, all tests were initially conducted as preliminary screens with retesting of outfalls which showed statistically significant differences from the control using Dunnett's procedure.

Statistical analysis. Mortality data from the study was analyzed by Dunnett's Procedure after transforming the square root of the proportion of dead organisms to an arc sine value. Dunnett's Procedure consists of an analysis of variance (ANOVA) to determine the error term, which is then used for comparing each of the treatment means with the control mean in a series of paired tests. The data was checked to ensure that observations were independent and normally distributed with homogeneity of variance. Normality was tested using a chi-square goodness of fit test, and homogeneity of variance was verified using Bartlett's Test (Horning and Weber, 1985; Snedecor and Cochran, 1980). Hatchability and relative percent teratogenicity were compared using a binomial distribution and a one-tailed t-test ($P \leq 0.05$).

During definitive testing, the chronic value was calculated using no observed effect concentration (NOEC) and the lowest observed effect concentration. The chronic value was derived by calculating the geometric mean of the highest concentration that caused no effect and the lowest statistically significant ($P \leq 0.05$) effect concentration for survival. Dunnett's procedure was used to evaluate definitive results, while Student's t-test was used to determined differences in hatchability, teratogenic response, and preliminary test survival.

Hydrology. The Grand Calumet basin is located in the northwestern corner of Indiana and adjacent areas of Illinois (Figure 1). The basin encompasses approximately 43,242 acres and is almost entirely contained within Lake County, Indiana (U.S. Environmental Protection Agency, 1982). The Grand Calumet River is bordered by the Little Calumet River to the south and Lake Michigan to the north. The east branch of the river originates at Marquet Park Lagoon, east of Gary, Indiana. From the headwaters, the river flows approximately 13 miles to the west, where it is joined by the river's west branch and empties into the Indiana Harbor Canal, approximately 3 miles east of the Illinois State Line. The Indiana Harbor Canal then flows north/northeast for approximately 5 miles and empties into southern Lake Michigan.

Flow within the system is sluggish and is estimated to average 16 cfs in the west branch and 880 cfs in the east branch (U.S. Environmental Protection Agency, 1982). Flow is sustained by high discharged volumes of cooling water derived from Lake Michigan, which is pumped to the river from USX. More then 90% of the flow originates as treated municipal and industrial wastewater, industrial cooling and process water, and stormwater runoff (U.S. Environmental Protection Agency, 1982). Frequent flow reversals are known to occur, extending into the west branch of the Grand Calumet River. The extent of flow reversals is dependent on the stage of Lake Michigan.

RESULTS

Public owned treatment works. Three publicly owned treatment works (POTW) representing the cities of Hammond, Gary, and East Chicago discharge into the Grand Calumet River. Prior to discharge, the Hammond Sanitary District (SD) uses a chlorine contact baffle system, while East Chicago SD and Gary POTW have holding ponds with final clarifiers.

During the preliminary screens, no significant sub-chronic mortality was observed in either the Hammond Sanitary District or Gary POTW effluents (Table 3). A teratogenic response was observed in 1.0% of the Gary POTW exposed larvae. East Chicago SD had a statistically significant deviation in survival from the control (t-values = 6.04). Significant teratogenic effects were observed in both 100% effluent concentrations of East Chicago SD and Hammond SD, with 33.3% and 7.2% of the larvae exhibiting a response, respectively. Hammond SD larvae possessed edematous yolk sacs and deformed mandibles, clear blood, and tumors on the nape and anterior trunk. Responses observed in East Chicago SD larvae included deformed crania and yolk sacs, absence of mandibles, body tumors, postcaudal body swellings, clear blood, and reduced heart beat.

The East Chicago SD was retested with fresh samples to determine dilution effects. No significant deviation in mortality (t-test; $P \geq 0.05$) was observed between any dilution and the control. Significant teratogenic responses were observed at all dilutions except 30% (Table 4). No detrimental effect was observed

TABLE 5. Industrial discharger definitive chronic embryo-larval testing results from the Grand Calumet River Basin during July and August 1986.

Effluent Concentration	Percent Hatchability	Relative Percent Teratogenicity Alive	Dead	Total	Survival A	B	x̄
Inland Steel 008							
0	100	0	0	0	90	98	94
3	99	0	1.0	1.0	98	94	96
10	94	0	2.1	2.1	88	78	83
30	100	0	0	0	100	96	98
60	96	0	2.0	2.0	96	86	91
100	84*	1	0	1.1	70	62	66*
Inland Steel 014							
0	100	0	0	0	90	98	94
3	97	0	0	0	94	98	96
10	100	1.0	5.5	6*	98	100	99
30	98	0	4.1	4.1	100	94	97
60	95	2.1	7.4	9.5*	56	80	68*
100	74*	5.4	2.7	8.1	2	0	1*
DuPont de Nemours							
0	96	0	0	0	96	98	97
3	95	0	2.1	2.1	96	86	90
10	98	0	2.0	2.0	100	96	98
30	98	35.7	30.6	66.3*	66	20	43*
60	98	65.3	1.0	66.3*	0	2	1*
100	97	65.9	0	65.9	0	0	0*

* Signifies a significant deviation from the control.

in hatchability among the three treatment facilities during either preliminary or definitive testing.

Industrial dischargers. Major dischargers in the Grand Calumet River—Indiana Harbor Canal include USX (previously U.S. Steel—Gary Works), LTV Steel, and Inland Steel. Only outfalls, which discharged contact, process, or treated water, were sampled. USX has 20 permitted outfalls discharging into the east branch of the Grand Calumet River, seven of which satisfied the above-stated criteria. LTV and Inland Steel discharge through 9 and 13 permitted outfalls, respectively, into Indiana Harbor and the Indiana Harbor Canal. Five outfalls were tested at LTV and Inland Steel. However, LTV Steel outfall 001 was non-operational, and outfall 008 has been permanently closed since 1979.

E.I. DuPont de Nemours and Company manufactures inorganic industrial chemicals, including herbicides and fungicides. DuPont discharges into the east branch of the Grand Calumet River through 3 outfalls and also utilizes the East Chicago SD. A single outfall (003) was sampled from E.I. DuPont.

Five of the seven USX outfalls did not elicite a sub-chronic mortality response. However, outfall 010 caused complete mortality of all test organisms, and 034 had limited survivorship (Table 3). Teratogenic responses were observed only in outfalls 010 and 030. Only the response at outfall 030 was statistically significant (t-test; $P \geqslant 0.05$) with 56.7% of the hatched larvae exhibiting a response. Teratogenic responses included clear blood, reduced heart beat, deformed mandibles, edematous yolk sacs, and swellings on the body. A significant difference in hatchability was observed only at outfall 034 (80% hatch). A USX strike prevented any additional definitive testing from being conducted during 1986.

LTV steel effluents did not exhibit any reduction in survival, hatchability, or teratogenic response during preliminary testing (Table 3). As a result, no additional testing was deemed necessary.

Preliminary testing of 3 of 5 Inland Steel outfalls did not elicite a sub-chronic response (Table 3). A statistically significant difference in survivorship was observed at outfall 008. Although greater mortality was observed at outfall 014, the result was not significant ($P \geqslant 0.05$) in a one-tailed Student t-test. The increased variance between the replicates was probably caused by a Type II error in accepting a false null hypothesis. A nonsignificant teratogenic response was observed at outfalls 002, 012, and 014.

Definitive sub-chronic testing of Inland Steel outfalls 008 and 014 was conducted with fresh effluent. A statistically significant difference in survivorship was observed in 100% effluent from outfall 008 and at concentrations above 60% for outfall 014 (Table 5). Outfall 008 had a NOEC of 60% effluent and a LOEC of 100% effluent. A chronic value of 77.5% effluent with a minimum significant difference (MSD) of 0.099 represented a 10.52% reduction in survival. A teratogenic response was exhibited in dilutions as low as 3% effluent at outfall 008 and was significant in dilutions as low as 10% effluent for outfall 014. Statistically significant responses in hatchability were found for 100% effluent at outfall 008 and 014.

E.I. DuPont de Nemours and Company outfall 003 caused complete mortality of newly hatched larvae after 120 hrs of exposure in the preliminary test (Table 3). DuPont effluent had no effect on the embryonic developmental stage, since no reduction in hatchability was observed. However, teratogenic response was not adequately assessed, since the larvae did not survive longer than 24 hrs after hatching. Definitive testing of fresh DuPont effluent confirmed the preliminary testing results (Table 5). Within 168 hrs of exposure, significant mortality was observed in concentrations above 30% effluent. A chronic value of 17.3% effluent was calculated from a NOEC of 10% and LOEC of 30% effluent. The MSD of 0.184 corresponded to a 18.92% reduction in survival. Hatchability during definitive testing was unaffected. However, teratogenic responses were observed in all concentrations. Statistically significant differences in teratogenic response was observed in dilutions above 30% effluent.

DISCUSSION

The general contaminated nature of the river sediments and overlying water column has been documented in the Grand Calumet River basin (U.S. Department of the Interior, 1966, 1967; U.S. Environmental Protection Agency, Technical Committee on Water Quality, 1970, 1982, 1985). Toxicants are known to be discharged from permitted point source outfalls into the river. Recent improvements in treatment technologies and effluent control have resulted in reductions of point

TABLE 6. Summarized chemistry data for Grand Calumet River Basin definitive embryo-larval chronic toxicity testing.

Effluent/		**East**		**Dupont**		**Inland Steel**			
Compound		**Chicago**		**003**		**008**		**014**	
		Total	**Dissolved**	**Total**	**Dissolved**	**Total**	**Dissolved**	**Total**	**Dissolved**
Metals	Ag µg/L	<6	<6	<6	<6	<6	<6	<6	<6
	Al	186	<80	<80	<80	<80	<80	<80	<80
	B	490	487	81	83	84	84	<80	115
	Ba	36	28	<6	30	19	19	<6	24
	Be	<1	<1	<1	<1	<1	<1	<1	<1
	Cd	—	—	—	—	<10	<10	<10	<
	Co	<6	<6	<6	<6	<6	<6	<6	<6
	Cr	<8	<8	<8	<8	<8	<8	<8	<8
	Cu	11	10	<6	7	7	7	21	21
	Fe	685	123	106	88	<80	<80	<80	2800
	Li	24	26	<10	40	<10	<10	<10	20
	Mn	118	112	<5	8	5	5	<5	65
	Mo	<15	<15	<15	<15	<15	<15	<15	<15
	Ni	<15	<15	<15	<15	<15	<15	<15	<15
	Sn	<40	<40	<40	<40	<40	<40	<40	<40
	Sn	<40	<40	<40	<40	<40	<40	<40	<40
	Sr	208	213*	<10	194*	116	116*	<10	147*
	Ti	<25	<25	<25	<25	<25	<25	<25	<25
	V	<5	<5	<5	<5	<5	<5	<5	<5
	Y	<5	<5	<5	<5	<5	<5	<5	<5
	Zn	81	<40	<40	58*	<40	<40	<40	141*
	Ca mg/L	72	74	<.5	158	35	35	<.5	45
	K	7	7	<.1	2	10	10	<.1	11
	Mg	17	17	<.1	2	10	10	<.1	11
	Na	221	218*	1	1700*	6	6	<1	14
	As µg/L	5	3	<20	<20	<2	<2	<2	<2
	Se	16	16*	<2	<2	<2	<2	<2	<2
	Cd	<1	<1	<1	<1	.2	.3*	.3	.6*
	Pb	17	11*	<2	<2	4	10*	81	25*
	Hg	0.2	0.3*	0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Hexavalent Chromium µg Cr/L		<10		<10		<10		<10	
Total Organic Carbon mg C/L		10		<3		<3		6	
Ammonia mg N/L		0.35*		<0.5		<0.5		<0.5	
Phenols µg Phenolics/L		30		26		28		40	
Total Cyanide µg Cn/L		300*		<5		<5		19	

Oil and Grease mg/L	<5	<5	<5	7
GC/MS semi -volatile				
Organic scan for priority pollutants	NS[a]	NS	NS	NS
VOA	NS	NS	NS	NS

[a] Data was either below detection or was not significant.

* Signifies that element or compound may be a toxic agent.

source loading rates. However, a substantial reservoir of these materials is contained in river sediments.

The control of toxic levels of compounds entering the river can be achieved by monitoring these outfalls. Chemical-specific criteria are a very expensive and intensive way of regulating toxic loadings and do not take into consideration the inhibitory, additive, or synergistic combinations possible in the receiving stream.

In the present study, analysis of water samples was initiated only on samples during definitive testing. None of the samples had detectable levels of volatiles, semivolatiles, oil and grease, or phenolics. Suspected contaminants identified included strontium, sodium, copper, zinc, selenium, cyanide, ammonia, mercury, and lead (Table 6).

Cyanide levels of 13.3 μg/L to 20.2 μg/L have been observed to cause chronic toxicity within fathead minnows (Lind, *et al.,* 1977). Cyanide levels of 300 μg/L were observed in East Chicago SD, and 19 μg/L in Inland Steel outfall 014. High cyanide levels apparently did not cause the toxic effect in East Chicago, since no significant mortality was observed. Cyanide may be a teratogen, since a response was observed in 33.3% of the preliminary screen larvae and in a mean of 66.5% of the larvae in definitive tests between 30% and 100% effluent.

Ammonia occurred at significant levels in East Chicago SD effluent and at Inland Steel outfall 014. Thurston, *et al.* (1986) found fathead minnow spawning affected at chronic ammonia levels ranging from 0.8 mg/L to 0.9 mg/L and reduced hatching success at 0.19 mg/L and higher. East Chicago SD ammonia levels were 0.35 mg/L, while Inland Steel outfall 014 levels were 0.49 mg/L.

Rainbow trout chronically exposed to lead concentrations of 27 μg/L during their early life stages developed spinal deformities in 32.2% of the fish (Davies, *et al.,* 1976). Total and dissolved lead levels were in close agreement for East Chicago SD and Inland Steel outfall 008 but were in disagreement at Inland Steel outfall 014 (Table 5). The dissolved level of lead at Inland Steel outfall 014 represented only 30.9% of total lead. Lead effects are inversely proportional to water hardness, with greatest toxicity observed at low hardness concentrations. Hardness levels at East Chicago SD and Inland Steel were about 5 to 7 times greater than the test conditions reported by Davies, *et al.* (1976). Sauter, *et al.* (1977) reported that lead amounts of 71 μg/L to 146 μg/L correspond to chronic toxicity effects in rainbow trout at a hardness value of 35 mg/L.

Zinc was observed to produce a chronic toxicity effect in laboratory testing in both hard water (Brungs, 1969) and soft water (Benoit and Holcombe, 1978), suggesting that zinc chronic toxicity may be relatively unaffected by hardness. Benoit and Holcombe (1978) reported chronic effects for fathead minnows using zinc in the range of 78 μg/L to 145 μg/L. Inland Steel outfall 014 had total zinc values of 141 μg/L. However, agreement between total and dissoved zinc (which was 3.5 times greater) did not exist. Zinc concentrations at outfall 014 were great enough to be of interest synergistically but not as an individual contaiminant.

Lind, *et al.* (cited in Stephan and Gentile, 1980) reported chronic effects to fathead minnows from copper in the range of 13.1 μg/L to 26.6 μg/L. The effect of copper on fathead minnows was not hardness dependent (Mount, 1968; Mount and Stephen, 1969; Pickering, *et al.,* 1977). A decrease in chronic toxicity with increasing hardness is suspected for most other species (U.S. Environmental Protection Agency, 1985). Total copper levels were 6.79 μg/L and 21.4 μg/L at Inland Steel outfalls 008 and 014, respectively. A dissoved copper value of 8.3 μg/L was found at outfall 008, while about half of the total copper occurred at outfall 014.

Call, *et al.* (1983) and Snarski and Olson (1982) reported mercury levels below 0.26 μg/L to have chronic toxicity impacts on fathead minnows. Effluent from East Chicago SD had dissolved mercury levels of 0.3 μg/L.

Salinity is known to enhance the chronic toxicity responses to otherwise nonharmful contaminents such as phenolics (European Inland Fisheries Advisory Commission, 1973). High sodium levels, with close agreement between total and dissolved sodium, at E.I. DuPont de Nemours outfall 003 may have enhanced the synergistic contribution of other contaminants.

The sublethal teratogenic effects observed in this study suggested that a synergistic combination produced the abnormalities at DuPont outfall 003. Copper and lead may have jointly contributed to observed teratogenicity at Inland Steel outfall 008 and 014. High levels of cyanide in East Chicago SD did not cause a reduction in survival but in conjunction with high ammonia levels may have caused significant teratogenicity. Thurston, *et al.* (1986) exposed fathead minnows from larval to adult stages to varying concentrations of ammonia. Swollen darkened areas on the heads occurred at concentrations of 0.21 mg/L NH_3 and higher, while observable growths, which often displaced the eyes, were visible at concentrations of 0.42 mg/L NH_3 and higher. Thurston, *et al.* (1986) reported a positive correlation between the occurrence of lesions and increased ammonia concentration. Gillespie and Baumann (1986) collected bluegill adults previously exposed to high levels of selenium and artifically cross-fertilized their gametes. Larvae exposed to high levels of selenium while undergoing embryogenesis exhibited edematous yolk sacs within 100 hr after hatching. These larvae were also less motile and died prior to reaching swim-up stage. Gillespie and Bauman (1986) suggested that their observations were due to transformation from the female to the eggs during oogenesis. Levels less than 30 μg/L did not cause significant mortality to carp, zebra danio, and rainbow trout during embryonic or larval stages (Huckabee and Griffith, 1974; Niimi and Latham, 1975; Goettl and Davies, 1978; Hodson, *et al.,* 1980). Gillespie and Baumann (1986) reported 100% edematous bluegill larvae in lakes which had an average of 10 μg/L selenium, a figure well below the water quality criterion for selenium of 35 μg/L.

Of equal importance in evaluating ambient teratogenicity is the finding of Birchfield (1987), who reported cranial anomalies from field collected specimens of gizzard shad and bluegill due to capture technique, fixation, or handling.

Hatching success was significantly inhibited only in 100% effluent from Inland Steel outfalls 008 and 014. Although neither copper or lead were at significant levels, the synergistic combination of these metals may have affected hatching.

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WATER QUALITY CHARACTERIZATION OF THE GRAND CALUMET RIVER BASIN USING THE INDEX OF BIOTIC INTEGRITY

Thomas P. Simon
U.S. Environmental Protection Agency
Central Regional Laboratory
536 S. Clark Street
Chicago, Illinois 60605
and
Greg R. Bright, Jerome Rud, and James Stahl
Indiana Department of Environmental Management
5500 W. Bradbury Street
Indianapolis, Indiana 46241

ABSTRACT: Water quality in the Grand Calumet River has shown steady improvement from 1985 to 1988 as determined by the index of biotic integrity (IBI), a measure of fish community health. Forty-three fish collections were made in the basin from 1985 to 1988, which resulted in a cumulative total of 21 fish species documented. The East Branch of the Grand Calumet River and Indiana Harbor Canal showed the most dramatic improvements from IBI ratings of very poor during 1985 to poor during 1987 in the Harbor. The West Branch showed a significant reduction in water quality with the decrease in Lake levels. Index of biotic integrity ratings of very poor were observed, during 1985, while no fish were collected in some areas during 1987 and 1988. The low water levels during drought conditions in 1988 influenced the entire river basin by reducing IBI values to baseline 1985 conditions and below.

INTRODUCTION

Instream quantification of impacts from point and non-point pollution sources on fish communities has been difficult to estimate. Separation of habitat degradation from organic enrichment and toxins has been especially difficult. Differences in professional interpretation of results and methodology have caused environmental regulatory agencies to reject biological evaluations for establishing permit limits for dischargers and has limited their utility. The recently developed index of biotic integrity (IBI; Karr, 1981; Karr, *et al.*, 1986) allows a more consistent application of biological sampling results and uses professional interpretation for categorizing water resource integrity.

Environmental problems within the Grand Calumet River basin have been documented (Federal Water Pollution Control Administration, 1966, 1967) and have concerned residents of northwestern Indiana for several decades. These chemical and sediment studies have documented where toxicants settled out in the basin, but little effort has been made to document the direct additive and syn-

TABLE 1. List of collection localities in the Grand Calumet River and Indiana Harbor Canal from October 1985 to July 1988. All stations are in Lake County, Indiana.

Station Number	Station Description
1	Marquette Park Lagoon, Miller, Calumet Township.
2	East Branch Grand Calumet River, E and W of Broadway from USX oil skimmer downstream, Gary, Calumet Township.
3	East Branch Grand Calumet River, W Bridge Street bridge, Gary, Calumet Township.
4	East Branch Grand Calumet River W Grant Street, Gary, Calumet Township.
5	East Branch Grand Calumet River, W Cline Ave. (SR 912), Gary, North Township.
6	East Branch Grand Calumet River, E Kennedy Ave, Gary, Calumet Township.
7	East Branch Grand Calumet River, adjacent Dupont de Nemours discharge canal including upstream segment, East Chicago, North Township.
8	Junction between the East and West Branch Grand Calumet River, Hammond-East Chicago, North Township.
9	West Branch Grand Calumet River, E Indianapolis Blvd. (US 20-SR 152), East Chicago, North Township.
10	West Branch Grand Calumet River, East I-90 bridge to eastern edge of Roxanna Marsh, East Chicago, North Township.
11	West Branch Grand Calumet River, East of Columbia Avenue to I-90 bridge, Hammond, North Township.
12	Indiana Harbor Canal, at Dickey Road bridge, East Chicago-Whiting, North Township.

ergistic effects on the resident aquatic community. The current study investigates the impact of water quality degradation and fluctuating Lake Michigan levels on the fish community of the Grand Calumet River basin.

METHODS AND MATERIALS

Karr, *et al.* (1986) established twelve metrics for categorizing biological integrity in streams. The cumulative total of these metrics comprise the IBI, with higher IBI values indicating ecologically healthier streams. The index is based on the premises that: 1) species diversity increases in a balanced community; 2) community dominance of tolerant forms indicates a stressed environment; 3) fewer top level carnivores and a higher proportion of omnivores are present in stressed environments; and 4) stressed conditions cause an increase in hybrids and disease within the community.

The prior use of the index has been limited to small streams and rivers and not to lake tributaries or harbors (Karr, *et al.*, 1986). The Grand Calumet River joins Lake Michigan via the channelized Indiana Harbor Canal, which is distinctly different from the east and west branches of the River. The harbor is dredged, and a 6 m channel is maintained for navigation purposes. The east and west branches are bordered by cattail marsh along the shores with depths usually less than 2 m. Neither of the branches are maintained for navigation, although they have been dredged in the past. Studies determined that species typical of the area could be categorized and the IBI metrics applied to the basin. Species considered

TABLE 2. Scoring criteria for second and third order reference stations comprising the northeastern Illinois watershed for calibrating the index of biotic integrity metrics (Gerking, 1946).

Metric	**IBI Scoring Criteria**		
	1	**3**	**5**
Species Diversity and Composition			
Number of Species - 2nd order	<6	6-10	>10
3rd order	<7	7-12	>12
Number of Sucker Species - 2nd order	<2	2	>2
3rd order	<2	2- 3	>3
Number of Sunfish Species - 2nd order	0	1	>1
3rd order	1	2	>2
Intolerant Species - 2nd order	<2	2- 3	>d3
3rd order	<2	2- 3	>3
Proportion of Green Sunfish	>20%	5-20%	<5%
Tropic Composition			
Proportion of Omnivores	>45%	20-45%	<20%
Proportion of Insectivores	<20%	20-45%	>5%
Proportion of Piscivores	<1	1-5%	>5%
Fish Abundance and Condition			
Number of Fish in a Sample[a]	<300	300-600	>600
Proportion of Hybrids	>1%	0-1%	0
Proportion of Individuals with disease, tumors, fin damage, and anomalies	>5%	>2-5%	0-2%

[a] Ratings based on electrofishing gear methods, as number of fish per hour.

transients and not reproducing in the river were excluded from metric scoring. The Grand Calumet River basin provides a unique opportunity to study a harbor tributary using the IBI.

The east and west branches of the Grand Calumet River, Marquette Park Lagoon, and the Indiana Harbor Canal were sampled at twelve stations (Table 1). Sampling was conducted by two collection teams during the spring, summer, and fall of each year from October 1985 to July 1988, using a DC electroshocker mounted either in a sport canoe or a Jon boat. Replicate sampling at three stations was conducted during the spring of 1987 to verify that representative samples were being collected by the two teams. Species were dip-netted as they were sighted, identified to species (Gerking, 1946; Nelson and Gerking, 1981; Trautman, 1981), weighed, measured for total length, and released.

The computer calculation of the index of biotic integrity was generated using the Illinois Environmental Protection Agency's BIBI water quality program (Kelly, 1986). The data used for calibrating reference stations was based on fish collections from the Illinois Department of Conservation (Table 2), using a watershed approach similar to the ecoregion concept of Omernik (1987). The Grand Calumet River and Indiana Harbor Canal are second and third order streams, respectively. The Grand Calumet River basin was scored against other typical drainages of similar size for the upper Illinois River system. The numerical score calculated from the index was compared to the attributes composed by Karr, *et*

TABLE 3. Total index of biotic integrity scores, integrity classes, and the attributes of those classes (modified from Karr, 1981; Karr, *et al.*, 1986).

Total IBI Score	Integrity Class	Attributes
58-69	Excellent	Comparable to the best situations without human disturbance; all regionally excepted species for the habitat and stream size, including the most intolerant forms, are present with full array of age (size) classes; balanced tropic structure.
48-52	Good	Species richness somewhat below expectations, especially due to the loss of the most intolerant forms; some species are present with less than optimal abundances or size distributions; tropic structure shows some signs of stress.
40-44	Fair	Signs of additional deterioration include loss of intolerant forms, fewer species, highly skewed trophic structure (e.g., increasing frequency of omnivores and green sunfish or other tolerant species); older age classes of top predators may be rare.
28-34	Poor	Dominated by omnivores, tolerant forms, and habitat generalists; few top carnivores; growth rates and condition factors commonly depressed; hybrids and diseased fish often present.
12-22	Very Poor	Few fish present, mostly introduced or tolerant forms; hybrids common; disease, parasites, fin damage, and other anomalies regular.
0	No Fish	Repeated sampling finds no fish.

al. (1986) to determine the river reaches biological integrity based on the stability of the fish community (Table 3).

RESULTS AND DISCUSSION

Species composition. Meek and Hildebrand (1910) documented the species historically present in the Calumet area. They concluded that 29 species were present in the Little and Grand Calumet Rivers, Deep River, Wolf Lake, Calumet Lake, and Lake George. With the introduction of the alewife, grass carp, and coho and chinook salmon into the Great Lakes system, the total number of species within the basin became 33. A total of 22 species are attributed to the Grand Calumet River (Gerking, 1945; Table 4).

The current study documented the presence of 21 fish species within the Grand Calumet basin (Table 5). Although Marquette Park Lagoon is no longer connected to the River proper, we continued to include it as the headwater for the historic Grand Calumet River. The most dominant taxa included golden shiner (46.5%), goldfish (20.2%), and carp (15.0%). After the rise in Lake Michigan levels during 1986 and the subsequent steady decline, the River has been invaded by lake-dwelling species such as alewife, gizzard shad, emerald shiner, and rainbow smelt.

TABLE 4. Fishes collected by Meek and Hildebrand (1910) from the Grand Calumet basin and deposited in the Field Museum of Natural History.

Common Name	Species Name
Amiidae	
Bowfin	*Amia calva*
Cyprinidae	
Carp	*Cyprinus carpio*
Golden shiner	*Notemigonus crysoleucas*
Emerald shiner	*Notropis anthernoides*
Spottail shiner	*N. hudsonius*
Bluntnose shiner	*Pimephales notatus*
Catostomidae	
White sucker	*Catostomus commersoni*
Ictaluridae	
Channel catfish	*Ictalurus punctatus*
Black bullhead	*Ameiurus melas*
Brown bullhead	*A. nebulosus*
Yellow bullhead	*A. natalis*
Tadpole madtom	*Noturus gyrinus*
Esocidae	
Northern pike	*Esox lucius*
Grass pickerel	*E. americanus*
Umbridae	
Central mudminnow	*Umbra limi*
Centrarchidae	
Green sunfish	*Lepomis cyanellus*
Pumpkinseed	*L. gibbosus*
Bluegill	*L. macrochirus*
Black crappie	*Pomoxis nigromaculatus*
Percidae	
Yellow perch	*Perca flavescens*
Logperch	*Percina caprodes*
Scianidae	
Freshwater drum	*Aplodinotus grunniens*

Resident pumpkinseed and central mudminnow have exhibited steady decline in abundance since 1986.

The number of species collected annually increased in the basin between 1985 and 1987. Seven species were collected during 1985 (Simon, 1985), 13 species in 1986, 17 species in 1987, and 9 species during drought conditions in 1988. These species represented indigenous fauna and not transient species. The recent community represents a return to conditions similar to 1985.

TABLE 5. Collection of fishes from twelve locations in the Grand Calumet River and Indiana Harbor Canal from 1985 to 1988.

	1985					1986						1987										1988						
	EB[1]			WB[2]		EB				WB	IHC	EB						J[3]	WB		IHC	EB			WB	IHC		
Species	**2**	**5**	**7**	**10**	**11**	**1**	**3**	**5**	**6**	**9**	**12**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**12**	**3**	**5**	**6**	**9**	**12**	**Total**	**Percent Dominance**
Oncorhynchus kisutch																					1						1	0.04
O. tschawytscha															1												1	0.04
Salmo gairdneri											10										1						11	0.40
Dorosoma cepedianum												1	101		11	44			3		65						225	8.16
Alosa pseudoharengus												2									4		6	2			14	0.51
Cyprinus carpio	18	3	10	2		18	4	34	21	20	28	5	9	10	64	55	22	21	17		16	8	15	13			413	14.97
Carassius auratus	22	2	10	12			15	87	55	22	3		47	2	47	43	1			1	22	24	53	84		4	556	20.16
Carp x Goldfish hybrid																					1						1	0.04
Notemigonus crysoleucus	12	12	100				53	78	91		1	14	315	17	258	75	2	1	1		12	115	59	65			1281	46.45
Notropis atherinoides											5										2		14				21	0.76
N. spilopterus																					1		12				13	0.47
Pimephales notatus								1				1				4					10	3					19	0.69
P. promelas		1																			1						2	0.07
Osmerus mordax														1								1					20	0.73
Umbra limi		3										4	4	1	1	5	1					1					20	0.73
Ameiurus melas			1			1																					2	0.07
Lepomis cyanellus	3					2	4																				9	0.33
L/ gibbosus						1		13	23		1		5		25	28	1				8	10	2	29		3	149	5.40
L. macrochirus						5	1						2								2						10	0.36
Pomoxis nigromaculatus						1																					2	0.04
Micropterus salmoides						2																					2	0.04
Perca flavescens											1	2	1								2						6	0.22
Number of Species	4	5	4	2	0	7	5	5	4	2	7	7	8	5	7	7	5	2	3	1	14	6	7	5	2	0	21	
Number of Collections	1	1	1	1	1	1	2	2	2	2	2	1	3	1	3	2	1	1	3	1	2	2	2	2	2	1	43	

[1] EB = East Branch [2] WB = West Branch [3] J = Junction

TABLE 6. Index of biotic integrity values for forty-three fish collections conducted in the east and west branches of the Grand Calumet River and Indiana Harbor Canal (IHC) from 1985 to 1988.

	Index of Biotic Integrity Value by Station											
	East Branch							Junc.	West Branch			IHC
	1	2	3	4	5	6	7	8	9	10	11	12
1985												
October		24			24		24			24	0	
1986												
June	32		26		24	24			22			24
October			28		30	28			20			26
1987												
April[a]		30	32	24	22		22	22	24	24		
April			24		24	26			22			28
November			32		30	30			0			34
1988												
May			26		22	24			0			
July			28		32	26			0			24

[a] Two collection teams sampled in April one day apart.

Carp comprised 88% of all collections, followed by golden shiner and goldfish, each comprising 76% of the collection. Coho and chinook salmon, rainbow smelt, black crappie, and a carp x goldfish hybrid were all represented by a single specimen (Table 5).

Index of biotic integrity. Annual changes in fish community composition are reflected in fluctuating IBI values each year. During 1985, the east and west branches of the Grand Calumet River had a water quality rating of very poor. IBI values increased by several points in the summer of 1986, coinciding with rising Lake Michigan levels. By autumn 1986, IBI values increased an additional two to four points (Table 6). This raised the water quality classification from very poor to poor. Another factor in the improved water quality in the east branch may be the strike at USX corporation. The shutdown of the facility had dramatic impacts on the east branch, since the facilities discharge provides as much as 95% of the flow (U.S. Environmental Protection Agency, 1985). With the lowering of lake levels during 1987, the dilution of toxicants in the East Branch channel enabled additional fish species to use the river.

The reverse relationship was observed in the west branch. When Lake Michigan levels dropped, the average depth of the river decreased, while the surface to volume exposure ratio of the sediment to the water column increased. IBI values dropped drastically at Indianapolis Boulevard and within Roxana Marsh. During the 1988 drought, the low depth in the west branch prohibited any species use of the river from Indianapolis Boulevard to the Interstate I-90 bridge. Discharge was less then the reported 7Q10 estimated for the west branch, and flow was eastward to the Indiana Harbor Canal from Columbia Street bridge. Much of the Roxanna Marsh dried up, and only a small channel remained through much of the summer. No fish were collected in the west branch in 1987 and 1988 from

Indianapolis Boulevard to the Interstate bridge. The east branch has improved and now supports the best portion of the Grand Calumet resident community.

Seasonal trends. The Grand Calumet River typically has highest utilization by age group 0 fish, some transient pioneer species from Lake Michigan. Summer IBI values either remained constant or improved slightly over the duration of this study. Fall values for all east branch stations increased from 1985 to 1987, while spring values declined from 1987 to 1988 (Table 6).

IBI values based on duplicate collections on successive days in the spring of 1987 were relatively consistent for two of three stations. The Bridge Street location was the only station, which deviated significantly between collection teams (Students t-test; $p \leqslant 0.05$). Species composition was similar, but the numbers of each species differed. In a stable environment, this would not be a problem, because of the presence of more species. However, due to low diversity and dominance by tolerant taxa, a profound impact was produced, when a shift toward tolerant taxa occurred. Another problem may have been an inadequate period for mixing between the first and second collections.

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GEOLOGY AND GEOGRAPHY

Chair: Thomas Miller
Department of Geography and Geology
Indiana State University
Terre Haute, Indiana 47809

Chair-Elect: Nelson Shaffer
Indiana Geological Survey
611 North Walnut Grove
Bloomington, Indiana 47405

ABSTRACTS

Earth Science Teaching in Indiana—Twenty Year Later. Roger F. Boneham, Dept. of Geology, Indiana University Kokomo, Kokomo, IN 46904-9003. ——Earth science teaching in Indiana public schools began in earnest during the 1960's. This paper is a follow-up report on the progress that has occurred in the twenty years that have elapsed since my original study. The typical earth science teacher has changed over the last twenty years. There are more women in the field, and the teachers are more likely to have at least one of their degrees in earth science. They are generally older and have been in the teaching profession longer than those of the earlier study. The calibre of their students has remained about the same with the majority being in the upper half of their class. The main problem areas for the teachers are: lack of student interest, low ability of the students, and lack of equipment. This was similar to twenty years ago. Increased funds for more laboratory equipment should be cost-effective since much of the material could be used to add an advanced earth science course. Many students could use this advanced course as their second year of high school science.

Historical Evolution of Surface-Mine Grasslands in the Illinois Coal Basin. Timothy S. Brothers, Department of Geography, IUPUI, 425 Agnes St., Indianapolis, IN 46202.——Archival records from state reclamation departments and the coal industry show that artificial grasslands have become a prominent new vegetation type in the Illinois Basin. Most of these grasslands have been planted during the last half century as surface-mine legislation and other factors have made grassland reclamation easier and cheaper than the reforestation that dominated early reclamation efforts. Throughout the Illinois Basin surface-mine grasslands are composed almost entirely of a few Eurasian forage species, most prominent of which are tall fescue, orchard grass, clovers, and lespedezas. The genetic variability of these species is generally small, because plantings are typically restricted to one or two favored varieties. Little effort has yet been made to use native species or to restore prairie to mined lands. Though most surface-mine grasslands are used at least sporadically for beef pasture, their long-term economic and ecological stability is uncertain because of regional decline in the livestock industry, low grassland diversity, and the abundance of potential woody invaders.

Bias in Coal-Sample Sources and Its Implications in Estimating Coal-Resource Quality. Walter A. Hasenmueller, Louis V. Miller, and Jimmy J. Johnson, Indiana Geological Survey, Bloomington, IN 47405.——The Coal Analysis

Database of the Indiana Geological Survey contains biases introduced by the preponderance of samples that Survey geologists collected from the working face in mines. To assess bias magnitude, we compared proximate analyses of 269 Indiana mine and non-mine samples of the Springfield Coal Member (Petersburg Formation). Bias is most obvious in moisture-free ash and coal thickness. Ash averages 16.7 and 10.8 percent in non-mine and mine samples. Ash-content spread is greater in non-mine than in mine samples (standard deviation (SD) = 6.9 versus 3.2 percent). Coal-thickness measurements show similar differences (mean = 4.0 and 4.9 ft, and SD = 2.2 and 1.4 ft). Volatile matter, fixed carbon, and heating value (Btu) show slight differences in mean and SD for the entire sample set, indicating no significant bias. Sulfur bias seems to be time dependent because mean sulfur in mine site samples drops steadily following the Clean Air Act of 1970, which placed a premium on low-sulfur coal. These biases suggest that sample sources must be considered when evaluating the quality of coal resources.

Black Riveran (Ordovician) Conodonts from the Marmora Area, Ontario Lowlands, Canada. ROBERT B. VOTAW, Department of Geosciences, Indiana University Northwest, Gary, IN 47408.——Conodont elements have been recovered from 35 samples collected at two well exposed sections of Black Riveran limestones near Marmora in the lowlands of southern Ontario, Canada. Nineteen meters of limestone are exposed in the Ontario Highway 7 roadcut at Marmora and 44 meters are exposed in the abandoned Marmoraton iron ore pit three kilometers southeast of Marmora in the most complete section of Black Riveran strata in the Great Lakes region. These strata have been interpreted as representing subtidal, intertidal, and supratidal environments (Mukherji, 1969; Walker, 1972). The collections are dominated by "fibrous" elements, typical of shallow water Ordovician sediments, but contain species characteristic of Sweet's (1984) *Plectodina aculeata, Erismodus quadridactylus,* and *Belodina compressa* chronozones. These chronozones encompass the type Black River Group of New York and equivalent strata throughout the Great Lakes region.

Geological Aspects of Sanitary Landfill Siting in Marion County, Indiana. TERRY R. WEST, Dept. of Earth and Atmospheric Sciences, Purdue University, West Lafayette, IN 47907.——Since 1983, the author along with several graduate students has had the opportunity to evaluate four distinctly different landfill sites in Marion County, Indiana. Geology and hydrology of the four sites have illustrated a considerable variation among these sites. Two basic landforms are present in Marion County, the White River floor plain including its tributary streams, and the extensive Tipton Till Plain of Wisconsin age which bounds the White River complex. Landfill sites studied were divided evenly between the two landforms, with two sites located in each. Of the four sites, only one is an on-going sanitary landfill, South Side Sanitary Landfill on Kentucky Avenue near the Indianapolis Stockyards. The two sites located on the Tipton Till Plain involved proposed landfills in Decatur Township in southwestern Marion County and another in Lawrence Township in the east central part of the county. The fourth site is the ash monofill for the new mass burn unit (incinerator) operated by the City of Indianapolis. This site lies within the White River flood plain, located at the Belmont Sewage Treatment Plant facility, south of downtown Indianapolis. Geologic and hydrologic details of the four sites will be compared and contrasted in the presentation.

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RELATIVE ACCURACY OF FOREST COVER CLASSIFICATION OF LAND USE AND LAND COVER MAPS FOR INDIANA

Steven E. Backs, Joseph A. Stratton, and Robert J. Haubry
Indiana Department of Natural Resources
Mitchell, Indiana 47446

INTRODUCTION

The Land Use and Land Cover (LUDA) digital map products are prepared by the U.S. Geological Survey (USGS) using data obtained from remote sensors on aircraft and satellites that are classified using rigid, standardized criteria (Anderson, *et al.*, 1976). LUDA digital data tapes provide a possible land use and land cover data source for developing Geographic Information Systems (GIS). LUDA maps (1:250,000-scale) are thematic quadrangles, depicting classifications of land use and land cover in a polygon format. The area covered by LUDA maps corresponds to that of USGS 1° to 2° topographic quadrangles of the same scale scale. A minimum mapping unit of 16 ha (40 a) is used for forest cover (Forest Land and Forested Wetlands); land with a timber-crown aerial density (closure) $\geqslant$ 10% not developed for other land uses or classified otherwise. Since many forest tracts in Indiana are $\leqslant$ 16 ha, the concern was that LUDA maps might underestimate the amount or proportion of forest acreage. Our objective was to verify the relative accuracy of the forest cover classifications for areas with less than 40% forest cover in Indiana.

STUDY AREAS

Two study areas with less than 40% forest cover were chosen from another study (Backs, 1987) to verify the accuracy of the forest cover classifications on LUDA maps. Each study area included 1 to 3 subsample units, which encompassed sites where the restoration of eastern wild turkey (*Meleagris gallopavo silvestris*) had been initiated. The subsample units allowed comparisons between the two map types over smaller areas with variations in the amount of forest cover and distribution. The study area in northwest Indiana (Northwest) included portions of Starke, Laporte, and Marshall counties. Three subunits encompassed wild turkey release sites at Jasper-Pulaski State Fish and Wildlife Area (Jasper-Pulaski); Winamac State Fish and Wildlife Area and Tippecanoe State Park (Winamac-Tippecanoe); and the Menominee State Wetlands Area (Menominee). The proportion of forest cover across the study area is low ($\leqslant$ 15%) and often exists as small discontinuous blocks or tracts ($\leqslant$ 16 ha). The small forest blocks were of particular interest to LUDA map verification, since they were smaller than the minimum mapping unit.

The southwest Indiana study area (Southwest) included portions of Warrick, Spencer, Pike, Dubois, and Gibson counties. The study area also included portions of the Patoka State Fish and Wildlife Area and Lincoln State Park. One subsample unit encompassed a wild turkey release site along the Little Pigeon Creek drainage (Pigeon Creek). The proportion of forest cover across the study area was generally 20-40%, existed in $>$ 16 ha blocks, and was relatively more continuous than found

TABLE 1. Forest cover amounts obtained from USGS LUDA maps and USFWS wetlands maps[1].

	Area	**Percent**	**Forest**
	Size	**Tract Size (ha)**	
Study Areas	**(km²)**	**Cover**	**(x̄; n)**
NORTHWEST INDIANA			
Menominee			
Wetlands Maps	199	10	6; 36
LUDA Map	211	23	149; 33
Winamac-Tippecanoe			
Wetlands Maps	82	14	19; 60
LUDA Map	87	24	109; 19
Jasper-Pulaski			
Wetlands Maps	93	15	28; 49
LUDA Map	105	35	242; 15
NORTHWEST TOTAL			
Wetlands Maps	1,062	5	11;435
LUDA Map	1,217	16	83;238
SOUTHWEST INDIANA			
Pigeon Creek			
Wetlands Maps	98	38	270;120
LUDA Map	109	33	257; 14
SOUTHWEST TOTAL			
Wetlands Maps	646	33	36;585
LUDA Map	713	33	428; 55

[1] U.S. Geological Survey's Land Use and Land Cover (LUDA) Maps (1:250,000); Chicago (1975-78); Vincennes (1977, 1980-81). U.S. Fish and Wildlife Service's Wetlands Inventory Maps (1:24,000); San Pierre, North Judson, Denham, Bass Lake, Culver, Rutland, Knox East, Knox West, Donaldson, Plymouth, Chrisney, De Gonnia, Bonnville, Lynnville, and Folsomville. All 1984.

in the Northwest. Descriptive maps of the study areas and subsample units are presented in Backs (1987).

METHODS

LUDA maps for Indiana were obtained from the National Cartographic Information Center, USGS. Forest cover (Forest Land and Forested Wetland classifications) polygons were manually highlighted with colored ink pens. Wetland maps (1:24,000) were aerial photo composites reproduced according to specifications of the U.S. Fish and Wildlife Service (1987). The area covered by each wetland map corresponds to that of each respective standard USGS topographic maps (1:24,000-scale). Forest cover < 2 ha is discernible and a minimum mapping unit for forest tracts on the wetlands maps was $\geqslant 5$ ha with $\geqslant 40\%$ timber-crown closure. Forest tract boundaries were delineated in pencil to make them more visibly defined. Other land uses $\geqslant 2$ ha contained within larger forest tracts were deleted from forest cover acreages. The amount of forest cover determined from the wetlands maps was considered the actual amount present for verifying the accuracy of the LUDA forest cover classifications.

Forest cover was manually measured on both types of maps using an electronic planimeter (Numonics, Model No. 1260). Data were compiled by study area and subsample units for respective comparisons.

RESULTS AND DISCUSSION

The proportion of forest cover and mean tract size were generally greater on the LUDA maps, especially when forest cover was <15% on the wetlands map (Table 1). The magnitude of these differences was also related to average forest tract size with more pronounced differences occurring where forest tracts existed as small, discontinuous blocks. This is quite evident in comparisons between the Pigeon Creek subunit of the Southwest to the subunits of the Northwest. Forest cover along the Pigeon Creek drainage exists as continuous strands or tracts as opposed to the small, isolated blocks often found on the Northwest subunits.

The broader criteria for classifying forest cover on the LUDA maps (i.e., ⩾ 10% versus ⩾ 40% timber-crown closure for the wetlands maps) would initially appear to contribute to an upward bias in the amount of forest cover on the LUDA maps. This discrepancy was considered a minor factor in classification differences, because most forest tracts on the wetlands maps had crown closures ⩾ 40%. Some small differences in the amount of forest cover depicted on the two maps probably resulted from the disappearance of timber during the time period when the two map types were completed. The LUDA maps were generally 5-6 years older than the wetlands maps. The slight discrepancies in the study area sizes were attributed to manual measuring errors and differences in map scales.

Overall, the accuracy of the LUDA maps improves as forest cover exceeds 30% and exists in larger, more continuous tracts. While not examined, LUDA maps may tend to overestimate the amount of forest cover (underestimate Agriculture land classifications) as the proportion of forest cover exceeds 70%. The biases of the LUDA forest cover classification are relatively minor and LUDA maps presently represent the most complete planimetric, digitized, data base for forest cover and other land uses in Indiana. LUDA maps and digital tapes are inexpensive, readily available, and could serve as useful data bases for regional forest land use applications to developing GIS technologies. Further verification and refinements in LUDA data bases will be possible as GIS technologies are employed by land use agencies in Indiana.

ACKNOWLEDGMENTS

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GLACIAL GEOLOGY AND GROUNDWATER FLOW IN NORTHERN AND CENTRAL INDIANA

Konrad J. Banaszak
1115 West 79th Street
Indianapolis, Indiana 46260

INTRODUCTION

Glaciologists in the past twenty years have made significant strides in understanding the patterns of deposition associated with glacial processes. These strides are not unlike the changes in geohydrology that we have witnessed in the same period in that they have been based on applying a new paradigm. In groundwater hydrology, quantitative modelling has allowed new predictions to be made about the response of complex systems to stress. In glaciology, a qualitative depositional systems model has allowed new predictions to be made about the continuity and variability of depositional units related to environments associated with glaciation. Ashley, *et al.* (1985) give five environments of deposition associated with glaciation: the subglacial, ice marginal, proglacial fluvial, proglacial lacustrine, and proglacial aeolian environments.

Deposits formed in these different environments also have different characteristics. Most importantly to geohydrologists, a certain predictability of sediment type and distribution is associated with each environment. This predictability allows hypotheses to be framed and tested. Geohydrologic tests of stratigraphic hypotheses can be performed, as well as conventional geologic tests such as coring and test drilling. For example, the interconnectedness of sands in a dominantly till setting is more easily evaluated by geohydrologic tests than by stratigraphic tests. The continuity of fine-grained deposits in a coarse setting, however, is probably more easily resolved using stratigraphic tests. The importance of understanding the depositional environments of glacial sediments is that it provides conceptual models for the spatial distribution and geometry of the various sediment bodies.

This paper presents four case studies from Indiana. These cases, however, do have analogues in the States adjacent to Indiana. The first two of these cases concern dominantly fine-grained deposits in four of the glacial environments. The final two are in dominantly coarse-grained deposits in the proglacial fluvial environment.

PROGLACIAL LACUSTRINE WITH SUBGLACIAL AND ICE MARGINAL ENVIRONMENTS IN NEWTON AND JASPER COUNTIES

A droughty, sandy soil in Newton and Jasper Counties had supported scrub oak and cattle grazing before a corporate farm was developed to change the land to row-crop production. The row crops were irrigated with groundwater from bedrock. Bergeron (1981) studied the geohydrology of the area, and Figure 1 is taken from his report. The surficial deposits consist of aeolian sand (deposited initially in a proglacial aeolian environment) over sand and gravel (proglacial fluvial environment). These coarse sediments are underlain by till (subglacial and ice marginal environment) and lacustrine clays (proglacial lacustrine envi-

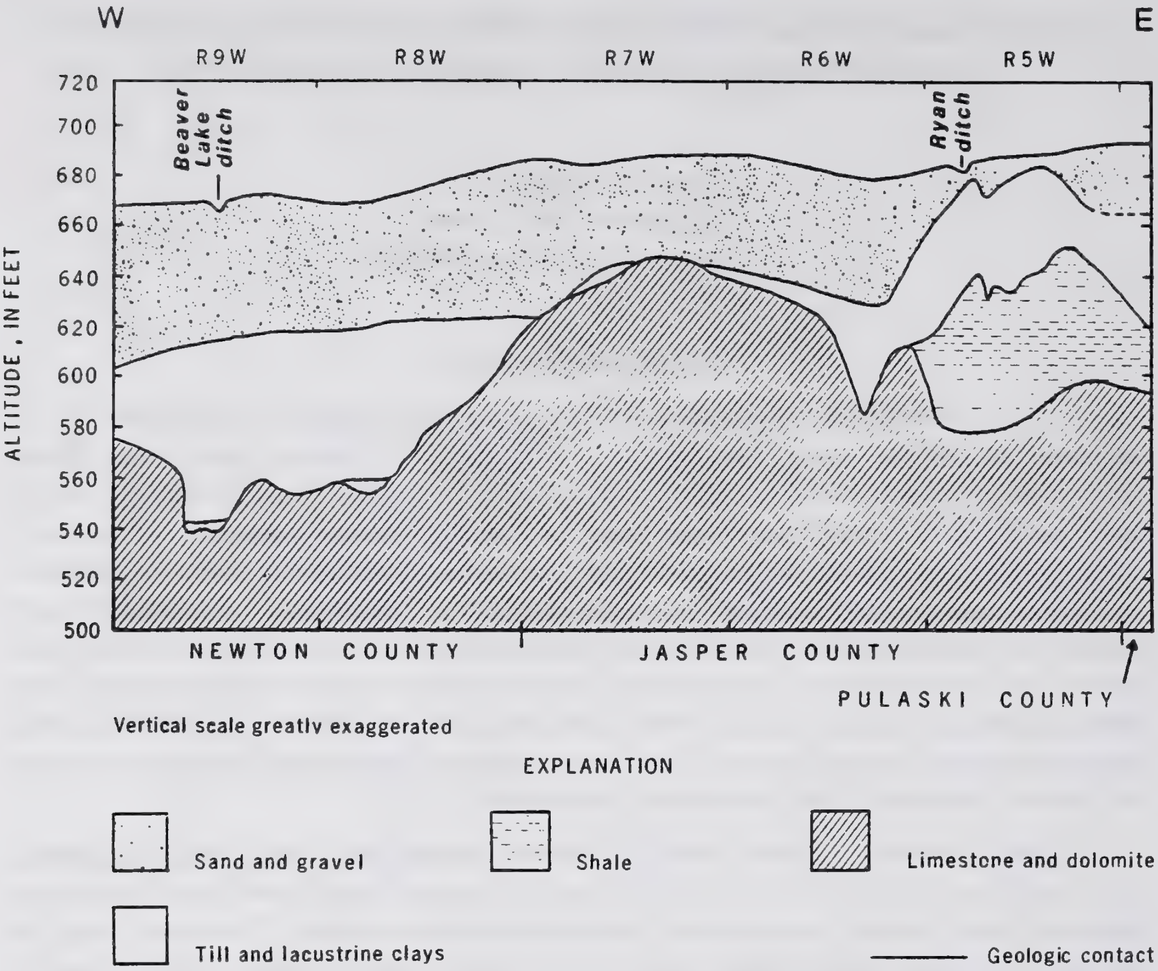

FIGURE 1. A west-to-east cross section from near the state line across Newton and Jasper Counties, Indiana (Modified from Bergeron, 1981, p. 12).

ronment) deposited on the bedrock. The bedrock is generally Silurian carbonate with fracture permeability, although there are some Devonian shales in places. Bergeron (1981) treated the till and lacustrine clays as a single semiconfining bed that allowed only vertical leakage between the overlying sands and the underlying bedrock aquifer. He assigned no storativity to this layer. In the ground-modellers lexicon, the till and lacustrine sediments were treated as a Tk layer.

Bergeron's (1981) model of the system was calibrated to a limited set of data gathered before irrigation began. The model predicted the response of the bedrock, the aquifer used for irrigation, reasonably well. The model, however, predicted declines in water levels in the surficial materials of several feet, after the irrigation pumpage started. Such declines in the surficial aquifer have not been observed to date (Basch and Funkhouser, 1985). The discrepancy between the observed and simulated responses is caused by the neglect of the storativity of the semiconfining materials. In the model, the recovery of the water levels in the bedrock aquifer was caused in part by leakage from the surficial aquifer through the semiconfining material.

As a result of the model's failure to predict accurately the changes in water levels in the surficial aquifer, a new study was begun with the focus being to investigate the storativity of the semiconfining beds. That study is still underway,

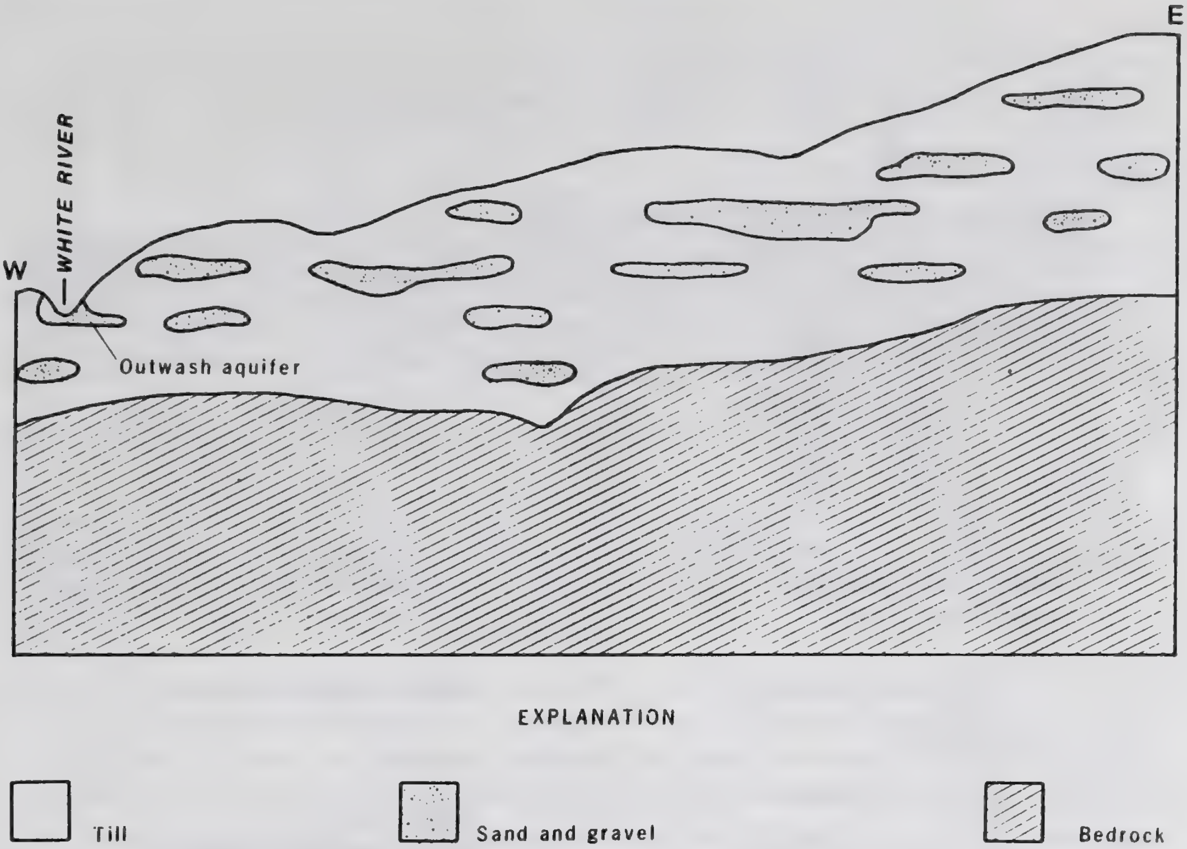

FIGURE 2. A west-to-east cross section across southern Delaware County, Indiana (Modified from Arihood and Lapham, 1982, p. 8).

but the importance of the distinction between the till and the lacustrine material is clear. While drillers commonly call the lacustrine material clay, it does contain a significant amount of silt and fine sand. But pity the poor geohydrologist trying to map the extent of till and lacustrine material on the basis of drillers logs. This interpretation is precisely the strength of new techniques in glacial stratigraphy. Using a limited set of gamma logs, the counsel of glacial stratigraphers, the predictive abilities of depositional-systems models in glacial terranes, and a knowledge of the hydraulic responses of materials in the field, the project personnel are taking the change in materials in the semiconfining beds explicitly into the model which is now being constructed.

It is too early to give out quantitative results. The project team, however, has decided that some recharge to the bedrock does come from storage in the semiconfining beds (Les Arihood, U.S. Geol. Surv., personnal communication, 1987). The long term question yet to be answered, of course, is what will happen when the stored water is used. If the water then will be derived ultimately from the overlying surficial materials, Bergeron's (1981) model predictions in the gross sense still will prove to be true.

SUBGLACIAL AND ICE MARGINAL ENVIRONMENTS IN THE UPPER WHITE RIVER BASIN

The form, distribution, and interconnectedness of sands and gravels within till sequences is a difficult problem. Aquifers of this type commonly yield 10 to

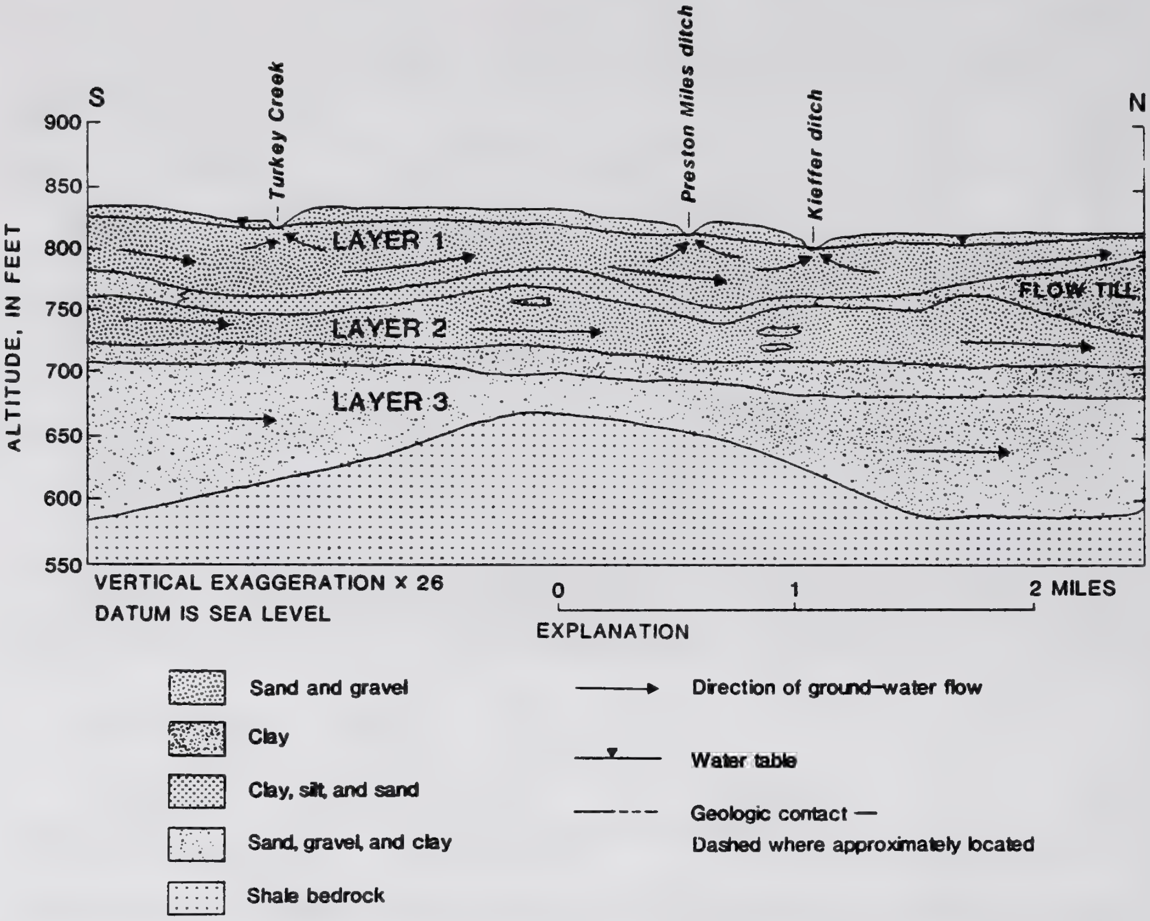

FIGURE 3. A south-to-north cross section across the border between Elkhart and Kosciusko Counties, Indiana (Modified from Lindgren, *et al.*, 1985, p. 12).

100 gallons per minute with exceptional wells yielding in excess of 400 (Banaszak, 1985). Arihood and Lapham (1982) studied this type of system in Delaware County, and Figure 2 is taken from their report. As can be seen, the sand as well as sand and gravel units were treated as basically isolated lenses of reasonably large extent. These units coalesce locally (Arihood and Lapham, 1982) to form more vertically extensive aquifers than are shown in Figure 2. Meyer, *et al.* (1975) were the first geohydrologists to work on this problem quantitatively in Marion County in Indiana. All workers are impressed with the difficulty and variability associated with these inter- and intratill aquifers.

In spite of the difficulties, reasonably accurate predictions of the quantity of water moving in these systems have been made. Additionally, in Marion County, the success of predicting the depth to and thickness of the first producing zone based on the maps of Meyer, *et al.* (1975) has been very good. The usefulness of similar maps by Arihood and Lapham (1982) has also been confirmed (Allen Samuelson, Ball State Univ., personal communication, 1986).

Understanding the interconnections of the sand and gravel aquifers becomes important for the planning and siting of potential sources of groundwater contamination in the relatively favorable surficial setting of till plains. As yet, no study to assess this potential on other than a site-specific basis is underway. The success of the relatively crude maps to predict the quantitative hydrology suggest

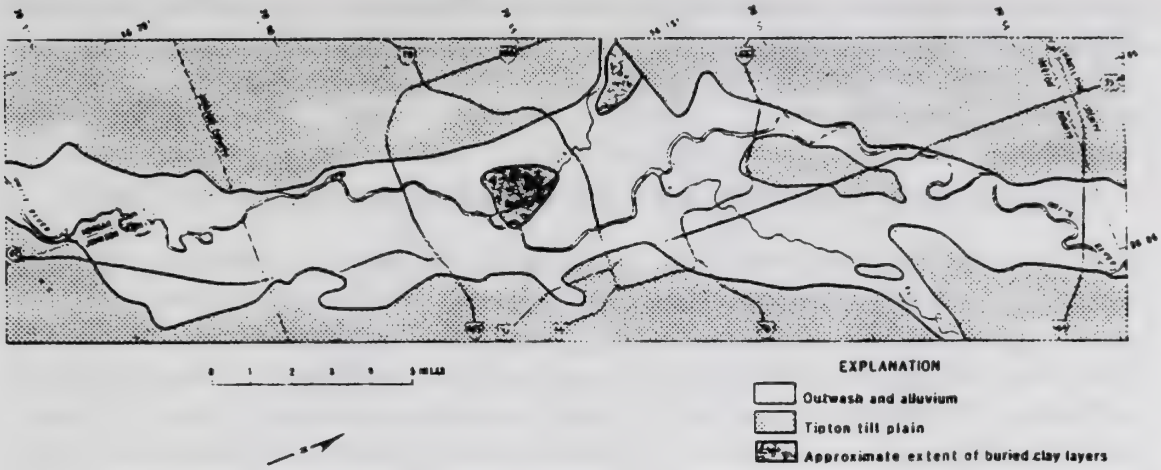

FIGURE 4. Outwash aquifer in Marion County, Indiana, showing the location of "buried clay layers" (Modified from Smith, 1983, pp. 12-13).

that the maps are reasonably accurate and are a good starting point. A study in which a geohydrologist and a glaciologist would interact has the most potential to produce an accurate understanding of the interconnectedness of these bodies on the scale of a county. In general, the glaciologist would provide the hypotheses for the geohydrologist to test quantitatively by the responses of the hydrologic system. The interplay should produce a new understanding of how to measure the interconnectedness and how to predict it.

PROGLACIAL FLUVIAL ENVIRONMENT IN ELKHART AND KOSCIUSKO COUNTIES

The question of continuity of fine-grained deposits provides the opposite question to that considered above. Lindgren, *et al.* (1985) considered that question for an area in northeastern Indiana, and Figure 3 is from their report. Early efforts used drillers logs and some gamma logs to decipher stratigraphic relations. These logs and the general initial bias of the investigators led to the construction of a one-layer 2-dimensional flow model for the area under investigation. This model treated the clay as lenses and hydraulically considered the clay as reducing the transmissivity of a node proportional to its thickness in that node. The 2-dimensional model could not be calibrated.

After discussions with a glaciologist (Ned Bleuer, Indiana Geol. Surv., personal communication, 1983), changes were made in the geometry of the fine-grained deposits. The changes were based on the interpretation of the upper fine-grained unit as a flow till. The critical information was provided by the gamma logs, although, in retrospect, the hydraulic information also could have led to the same change in geometry. The change clearly required a 3-dimensional flow model. The 3-dimensional flow model calibrated readily with the new geometry and apparently is an accurate representation of the flow in the area.

Other geohydrologists may have the same bias, especially when considering the relative ease of constructing a single-layer, 2-dimensional flow model as opposed to a 3-dimensional, 3-layer model. Not all fine-grained deposits are flow tills, but it is intriguing to speculate on how many flow tills may have been assumed wrongly to be limited lenses. In this case, the input of a glaciologist was extremely important as were the availability of gamma logs. In the proglacial environment, rapid changes are expected. But sometimes these changes in sediment type may be laterally more extensive than their thickness would at first lead us to suspect.

PROGLACIAL FLUVIAL ENVIRONMENT IN MARION COUNTY

Smith (1983), who constructed a digital model for the outwash of Marion County, also faced the problem of fine-grained material in coarse-grained outwash. Smith mapped four areas of significant "buried clay" on the basis of drillers' logs. These areas are shown in Figure 4. The area in the middle of Figure 4, near the confluence of White River and Eagle Creek, is being studied now (Bobay, in prep.). Above this area on the surface are a sewage treatment plant with attendant sludge lagoons, a large land-fill, a quarry and incline to an underground limestone mine, and several large industrial plants. With that potential for groundwater contamination, the nature of all the material below is important for defining flow paths, but even more so if there is significant fine-grained material.

The nature of the fine-grained material is not known now. Future study may include ground-penetrating radar, intensively filtered shallow seismic surveying, and more gamma logging. Hypotheses for the origin of the deposit include flow till, braided-channel deposits, and lacustrine deposits behind an ice dam near the mouth of present day Eagle Creek. One of these may be correct, but the correct hydrogeologic interpretation will require either a reasonable genetic hypothesis backed by present data supplemented with remotely sensed information or an extensive drilling program.

CONCLUSIONS

Four studies in northern and central Indiana underscore that an understanding of glacial geology is the most important variable in defining ground-water flow. In spite of the lack of modern analogues, students of continental glacial deposits have broadened their understanding by using the depositional systems approach. Because of the systems' predictive power, prudent groundwater hydrologists, who work in continental glacial terranes, should master these current concepts and judiciously apply them.

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SUBSURFACE BELT SANDSTONES IN THE HARDINSBURG FORMATION (LATE MISSISSIPPIAN) OF INDIANA

John B. Droste and Alan Stanley Horowitz
Department of Geology
Indiana University
Bloomington, Indiana 47405

INTRODUCTION

The purpose of this report is to present the general stratigraphy of the Hardinsburg Formation, Stephensport Group (Figure 1), in the subsurface of Indiana and to consider factors that have combined to create a belt of massive sandstones in the Hardinsburg in southwestern Indiana. These Mississippian rocks lie near the Lower Carboniferous Visean-Namurian series boundary of international terminology. The study area (Figure 2) is south of the northern boundaries of Sullivan and Greene Counties and west of the eastern boundaries of Greene, Martin, and Dubois Counties.

The data for this report were taken from well information on file with the Indiana Geological Survey, Bloomington (Table 1). Initially, the records of approximately 12,000 wells were inspected. A single well per section was selected for construction of the thickness maps, and no more than three wells per section were chosen to construct the cross sections. Intensive drilling for petroleum throughout much of the study area provides at least one well per section for which both well samples and a geophysical log are available. In areas of less dense drilling, we necessarily used wells for which either samples or wire-line logs existed.

PREVIOUS WORK

Reviews of Late Mississippian surface and subsurface stratigraphy and depositional systems in the Illinois Basin area can be found in Swann (1963,1964), Potter (1962,1963), Willman, *et al.* (1975), Sable (1979), and Shaver, *et al.* (1986). For treatment of the underlying West Baden Group in Indiana, see Sullivan (1972) and for the overlying Buffalo Wallow Group, see Droste and Keller (in press). Typical reconstructions of paleogeography during Mississippian time, based on paleomagnetic data, place Indiana between 5 and 10 degrees south latitude (Sable, 1983; Gutschick and Sandberg, 1979).

In his comprehensive classification of Late Mississippian rocks of the Illinois Basin, Swann (1963) enlarged on an earlier statement by Stuart Weller (1922) that a river (named the Michigan River by Swann) was the fluvial transport system for terrigenous sand and mud to sites of deposition in the Illinois Basin. The headwaters of the Michigan River were far to the northeast in the eastern part of the present Canadian Shield, and the Michigan River terminated in a birdsfoot delta situated in Indiana and Illinois. Swann (1964) subsequently proposed that elongate sand bodies in the Late Mississippian rocks were products of deposition as distributary mouth bars or finger bars resulting from the south-

MISSISSIPPIAN SYSTEM	BUFFALO WALLOW GROUP	GROVE CHURCH SHALE
		KINKAID LIMESTONE
		DEGONIA FORMATION
		CLORE FORMATION
		PALESTINE FORMATION
		MENARD LIMESTONE
		WALTERSBURG FORMATION
		VIENNA LIMESTONE
		TAR SPRINGS FORMATION
	STEPHENSPORT GROUP	GLEN DEAN LIMESTONE
		HARDINSBURG FORMATION
		HANEY LIMESTONE
		BIG CLIFTY FORMATION
		BEECH CREEK LIMESTONE
	WEST BADEN GROUP	CYPRESS FORMATION
		REELSVILLE LIMESTONE
		SAMPLE FORMATION
		BEAVER BEND LIMESTONE
		BETHEL FORMATION

FIGURE 1. Chart of stratigraphic nomenclature of a part of the Mississippian System.

westward progradation of the Michigan River birdsfoot delta. During regressions, the shoreline moved as far south as northern Arkansas, and during transgressions, the shoreline lay as far northeast as southern Ontario. The interpretation of extensive shoreline migration (Treworgy, 1988) continues to be a favored interpretation, but this model is currently being challenged. Droste and Keller (1989, in press) argue that not just one (the Michigan River) but at least three river systems (Figure 3) were necessary to explain the distribution of sandstone bodies in the post-Hardinsburg Buffalo Wallow Group and of the river systems that flowed on the pre-Pennsylvanian surface. They further indicated that almost all the middle and late Chesterian rocks were deposited in tidally dominated marine rather than fluvial dominated environments.

Potter (1962,1963) described and classified sheet and elongate sand bodies in Mississippian and Pennsylvanian rocks in the Illinois Basin. In this report, we use his classification of elongate sand bodies. Pods are isolated sand bodies whose lengths are less than twice their width. Ribbons commonly exhibit lengths much greater than twice their width, and belt sand bodies are measured in widths of miles and lengths of 10's to 100's of miles. Potter (1962,1963) illustrated the distribution of belt sandstones in the Hardinsburg and concluded that, although

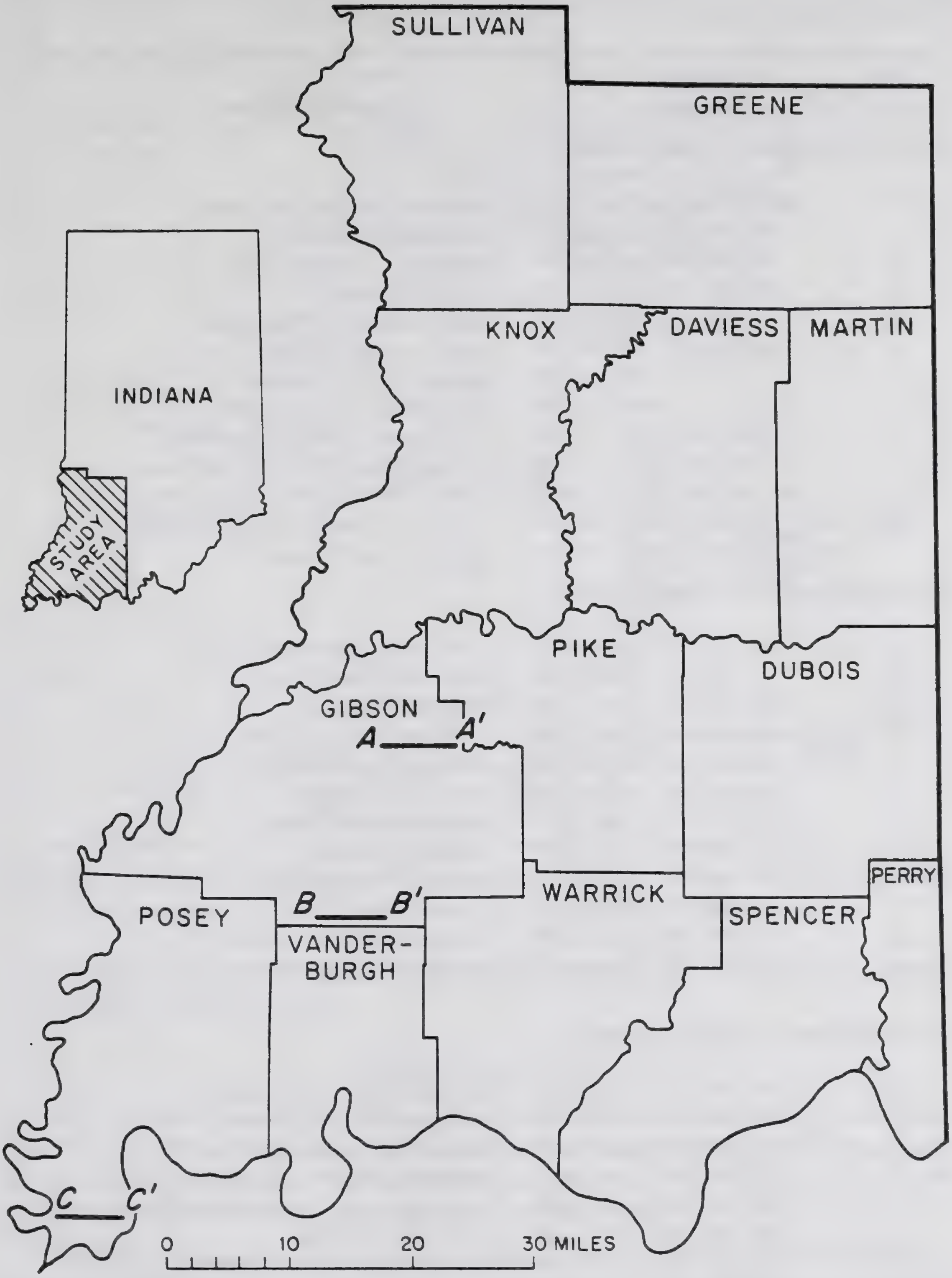

FIGURE 2. Map of study area and general location of the three cross sections (Figures 7-9).

the pattern of belt sand bodies was the principal feature of the system, the overall pattern resulted from a large distribution system in a delta.

Swann (1964) further suggested that cyclical surges of siliciclastic sediment resulted from climatically controlled rhythmic variation in rainfall. A shift to wetter climate with increased rainfall resulted in an increase of terrigenous load delivered to the basin. A shift to a drier climate resulted in a reduction of terrigenous sediment and permitted carbonate sedimentation to dominate across the

TABLE 1. Well locations.

Well No.	Well Location	Operator, Farm
Cross section AA′ (Gibson County)		
1.	NE NE SE 33-15-1S-10W	Cherokee Drilling #6 Kerzan
2.	NW NW SW 34-1S-10W	Collison #1 Kendle
3.	NE NE SE 34-1S-10W	Ecus Corp. #1 Dyer, *et al.*
4.	SW SW NE 35-1S-10W	Kidd #1 Shafer
5.	SE NW 36-1S-10W	George Trust #1 Clem, *et al.*
6.	NW NE SE 36-1S-10W	Ecus Corp. #2 Wilder
7.	SW 31-1S-9W	George Trust #1 Mahon
8.	SW 31-1S-9W	Paco Petroleum #1 Mahan
9.	SW SE SE 31-1S-9W	Mid-Central Prod. #1 Coleman
10.	SW NE SW 32-1S-9W	Jackson Wrather Oil #1 McConnell comm.
11.	SE NE SE 32-1S-9W	Kuzmich #4 McGill, *et al.,* comm.
12.	NW NW SW 33-1S-9W	Kuzmich #1 Smith & Clem. comm.
Cross section BB′ (Gibson County)		
13.	SE NW NW 10-4S-11W	Cherry #1 Epperson
14.	SE SE 10-4S-11W	H & H #1 Ziliak Farms
15.	SW NW SW 11-4S-11W	H & H #6 Spindler
16.	NE NE SW 11-4S-11W	So. Triangle #1 Spindler
17.	NE NE SE 12-4S-11W	Reliance #4 Goldsmith
18.	NW NE SW 12-4S-11W	Aurora #1 Lamey
19.	NE NE SE 12-4S-11W	Sandy Ridge #1 Knapp
20.	NE NW SW 7-4S-10W	Cleff #2A Knapp
21.	SE NE 7-4S-10W	Turner #1 Hirsch comm.
22.	SE NW SE 8-4S-10W	George #1 Keil
23.	NW NW SW 9-4S-10W	Universal Res. #1 Rhinhart
24.	SE SW SW 9-4S-10W	Desloge #1 Bittner Unit
Cross section CC′ (Posey County)		
25.	NE NW SW 17-8S-14W	Mid South Oil #1 Goldman
26.	SE SW NE 17-8S-14W	Gallagher #2 Gray Estate
27.	NW SW NW 16-8S-14W	Buttes #29 Oakland City Col.
28,	SE NW NE 16-8S-14W	Schoonmaker #1 Oakland City Col.
29.	NW NW NW 15-8S-14W	Schoonmaker #D-1 Oakland City Col.
30.	NE SE NW 15-8S-14W	Jarvis #1 Cronbach
31.	SW NW NW 14-8S-14W	Skiles #2 Vogel Althea Spencer, *et al.*
32.	SW NE NW 14-8S-14W	Rush Creek #4 Spencer
33.	SE NW NE 14-8S-14W	Rush Creek #1 Spencer Vogel
34.	NE NW SW 13-8S-14W	Rush Creek #1 East Klein St. of Ind.
35.	NW SW SW 18-8S-13W	Heath #3 Rosenbaum
36.	NW SE SW 18-8S-13W	Heath #3 Highman Hardwick
37.	NW SW SE 18-8S-13W	Fleming #1 Hardwick

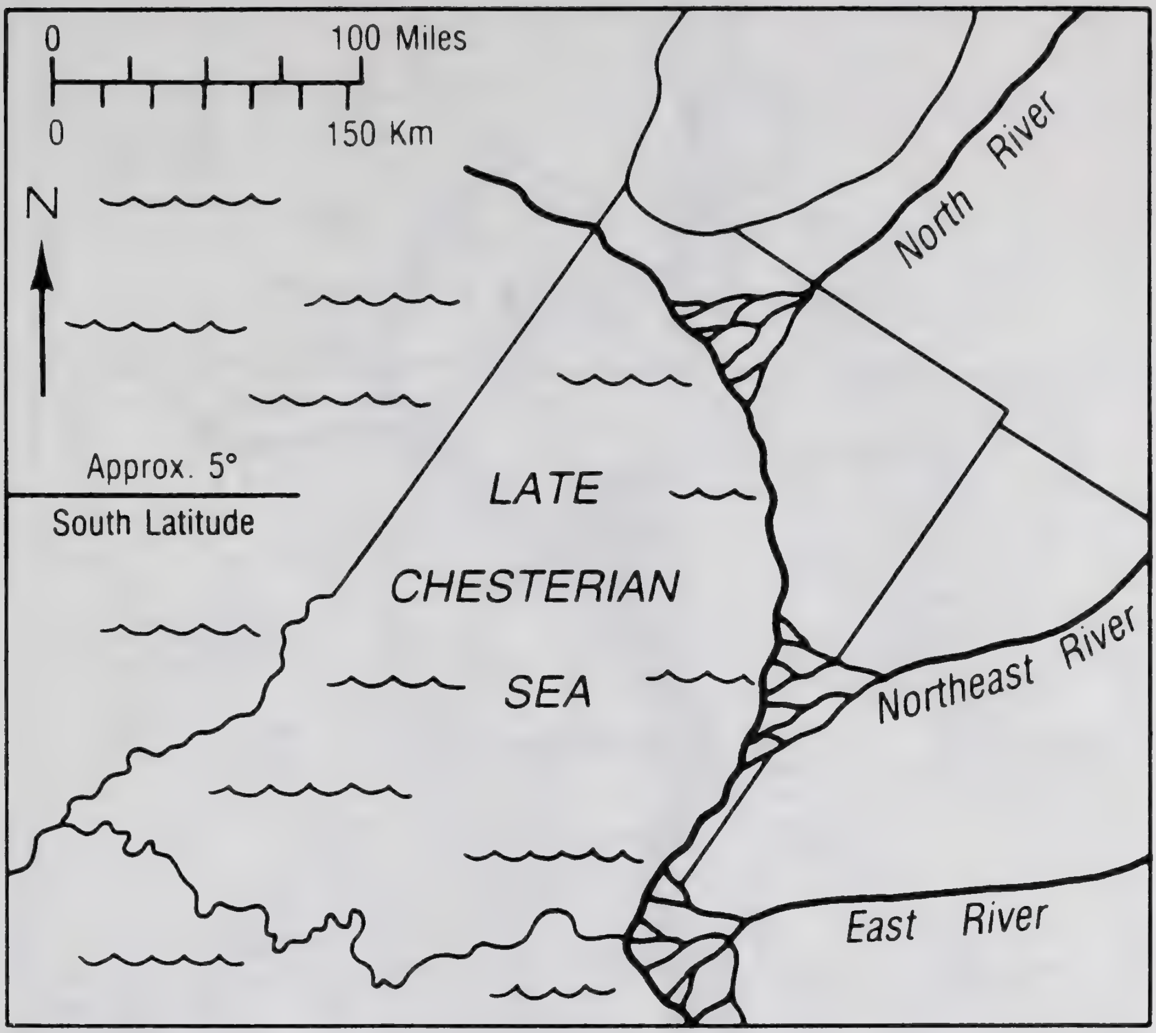

FIGURE 3. Map showing generalized paleogeographic reconstruction during a high level sea stand in Late Mississippian time (Droste and Keller, in press).

basin. With slight modifications, this general interpretation of sequential changes in lithology is followed herein.

STRATIGRAPHY

The Stephensport Group (Figure 1) is composed of, in ascending order, the Beech Creek Limestone, the Big Clifty Formation, the Haney Limestone, the Hardinsburg Formation, and the Glen Dean Limestone. See Shaver, *et al.* (1986) for the history and current usage of these terms in Indiana.

Haney Limestone. The Haney Limestone in Indiana increases in thickness from less than 20 feet near its northern outcrop and subcrop limit to almost 70 feet in southern Posey County (Figure 4). In the north, the Haney consists of a single interval of limestone containing thin interbedded layers of shale. Where the Haney is 40 or more feet thick, 2 to 5 massive beds of packstone, wackestone, and grainstone are interlayered with thin gray and green fossiliferous shale beds.

In an area from Knox County southwestward to Posey County, the Haney is thin and in a few places is absent. In this zone of thin Haney, the overlying Hardinsburg Formation is thickest (Figure 5), the amount of sandstone in the Hardinsburg (Figure 6) is greatest, and a high percent of massive packstone and some grainstone in the Haney is associated with the area of thick sandstone. For

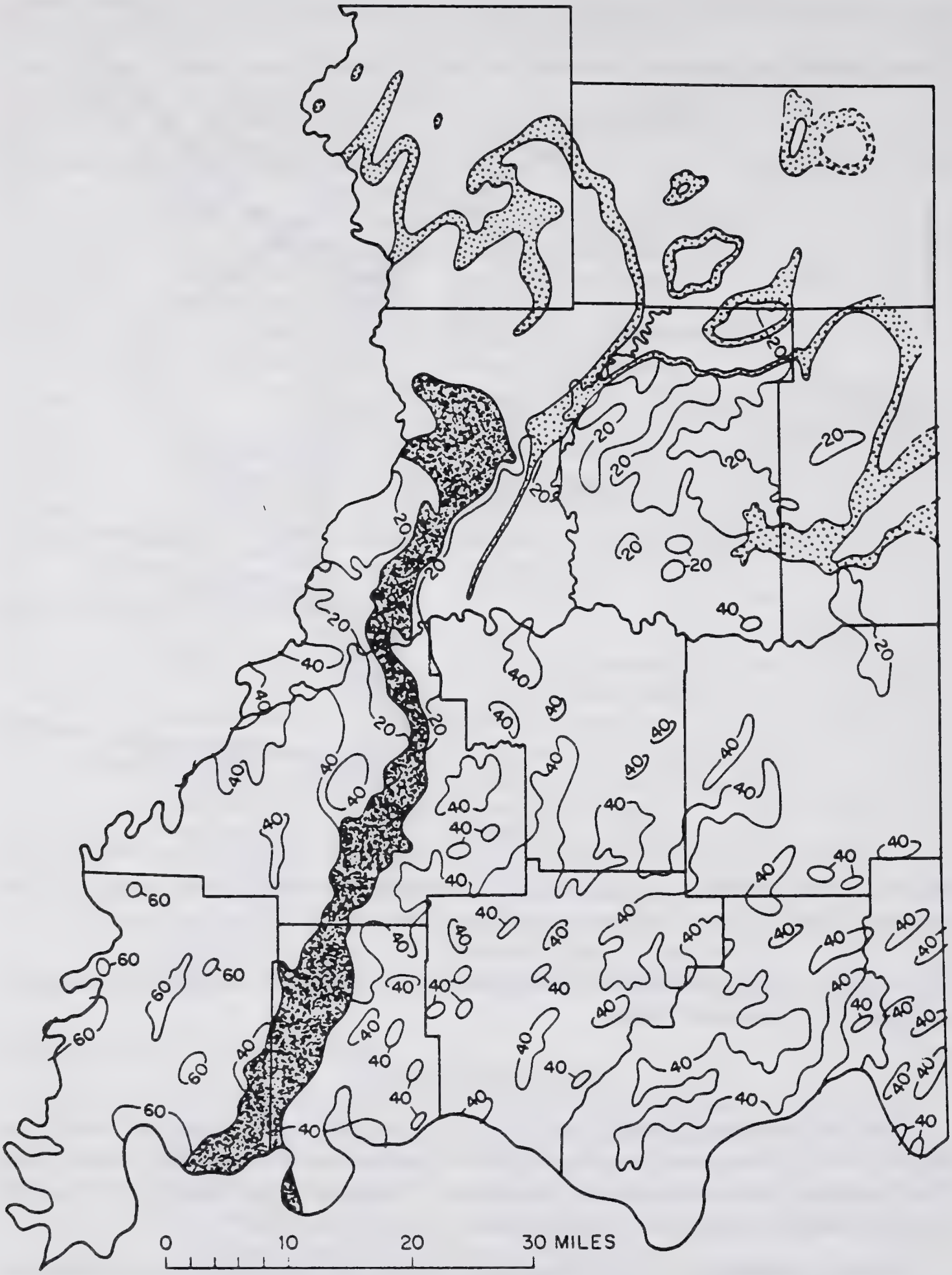

FIGURE 4. Map of thickness of Haney Limestone. The subcrop of the Haney is dotted. Area of thinned Haney (see text) is stippled. Countour interval is 20 feet.

a more detailed regional study of the Haney Limestone, see the recent report by Treworgy (1985). The contact of the Haney with the Big Clifty Formation below is conformable and sharp. The upper contact of the Haney with the Hardinsburg Formation is generally conformable and sharp. No cores are available for confirmation, but where the thick sandstone in the Hardinsburg lies directly on limestone of the Haney, the contact is probably a scoured disconformable surface. In

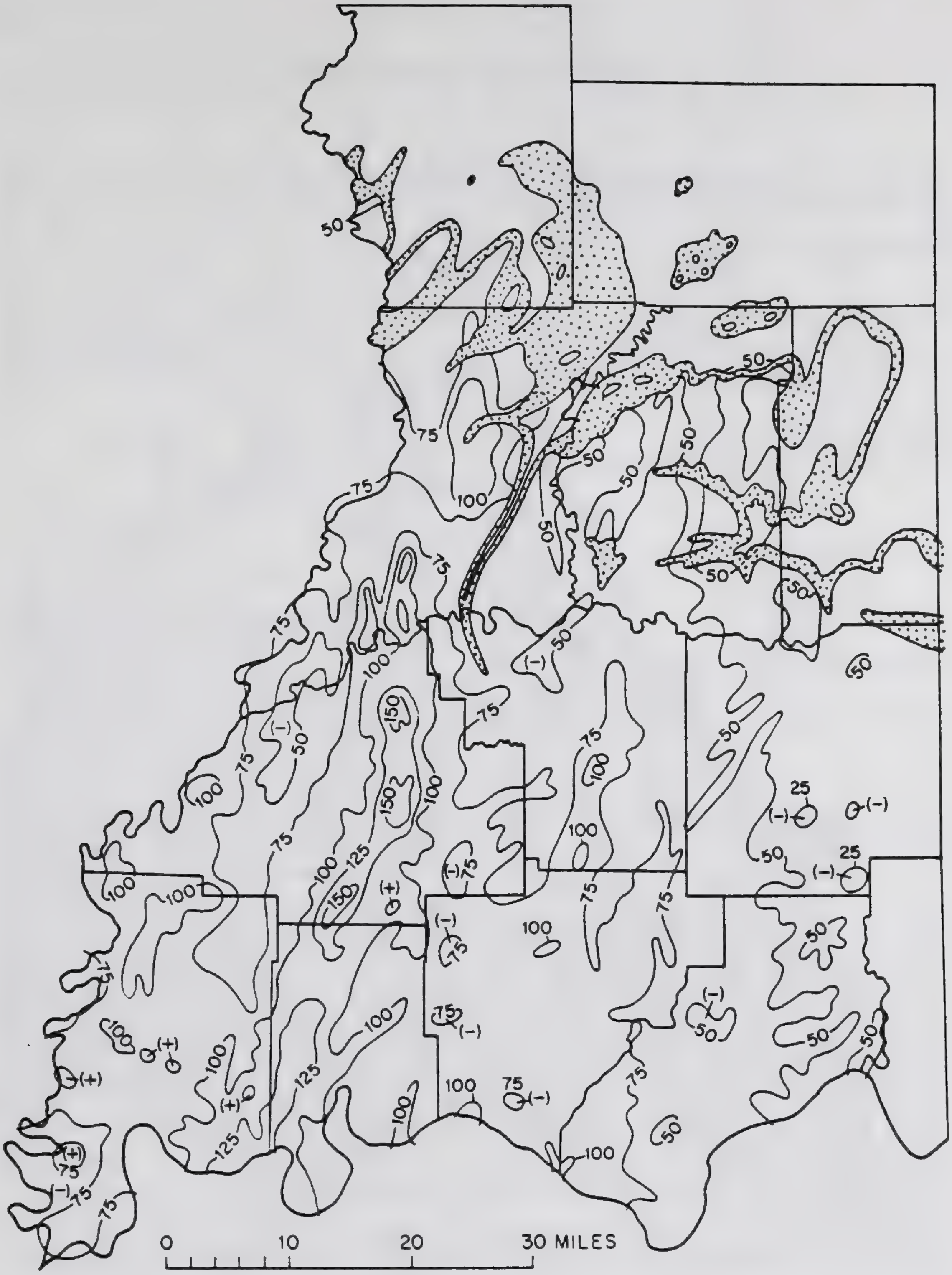

FIGURE 5. Map of thickness of Hardinsburg Formation. The subcrop of the Hardinsburg is dotted. Contour interval is 25 feet.

the area of subcrop (Figure 4) and in places along the outcrop, the Haney is unconformably overlain by rocks of the Pennsylvanian System.

Hardinsburg Formation. The Hardinsburg Formation consists of shale and sandstone and increases in thickness from less than 50 feet along the northern subcrop and eastern outcrop to nearly 175 feet in Gibson County (Figure 5). In

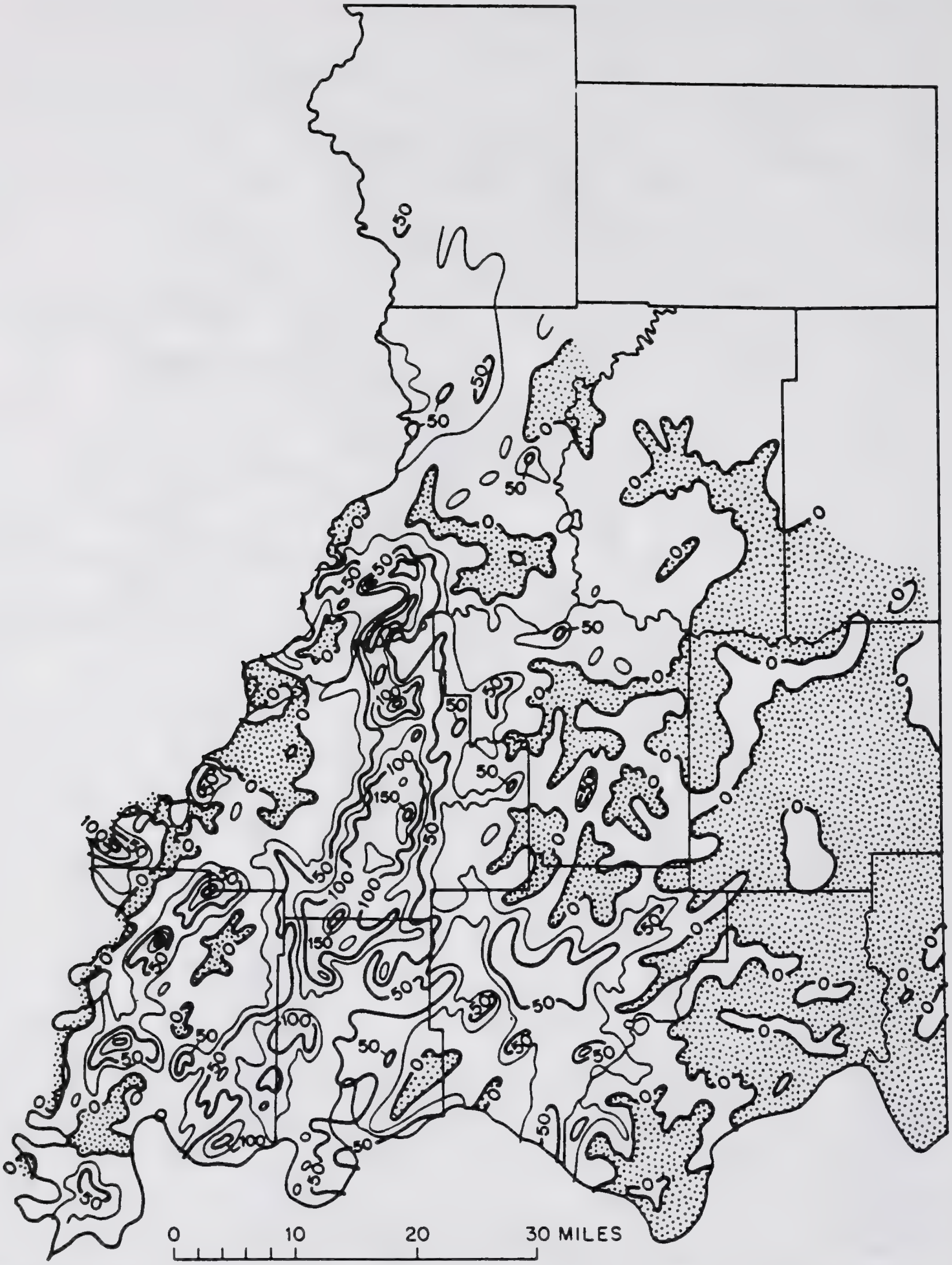

FIGURE 6. Map of net thickness of sandstone in Hardinsburg Formation. Areas where sandstone is absent in the Hardinsburg are dotted for emphasis. Contour interval is 25 feet.

several areas at the surface and in the shallow subsurface, particularly in Dubois County, the Hardinsburg Formation is less than 25 feet thick.

The Hardinsburg Formation is predominantly green and gray shale throughout much of the study area. A zone of red and maroon shale 5 to 10 feet thick in the upper part of the Hardinsburg is observed in many sample sets, and many

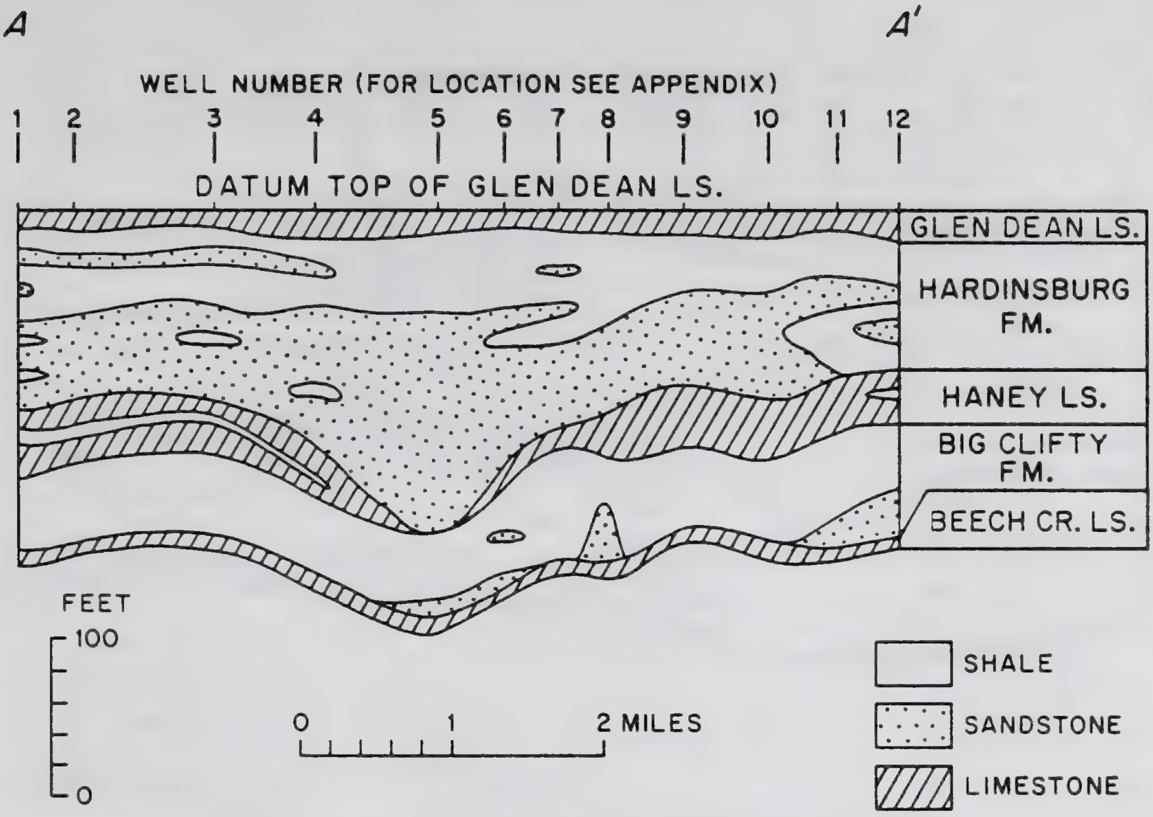

FIGURE 7. Cross section AA′. Location and other well information is given in Table 1.

driller's logs note the footage of this "red zone". The shales are very sparingly to moderately fossiliferous based on the observed abundance of fossil fragments in samples.

The net sandstone thickness in the Hardinsburg is less than 25 feet throughout most of the study area (Figure 6). A significant increase in sandstone thickness in very short distances in Knox, Gibson, Vanderburgh, and Posey Counties marks the location of belt sandstone bodies. In a detailed study of the sandstone bodies in several townships in Gibson County, Laurin (1988) documented the complexity of the belt sandstone and sandstone pods and ribbons in the Hardinsburg. The pod and ribbon quartz sandstone bodies are characteristically very fine grained, moderately sorted, and light brown, pale yellow-brown, or less commonly white. The quartz sand in the light colored belt sand bodies is fine grained and well sorted in the lower $1/2$ to $2/3$ of their thickness, and the sand is very fine grained and moderately sorted in the upper part of the body. Geophysical logs indicate that the belt sandstones are totally massive. In numerous places where the Haney Limestone is thin or absent (Figure 4), the lowest 10 to 20 feet of the belt sandstone is very limy and is almost a sandy limestone.

As seen in cross section, the generally massive belt sandstone bodies (Figures 7, 8) that lie directly on the Haney Limestone have irregular upper and lower contacts and, in some places, contain interbedded shale. In other areas (Figure 9), a significant shale interval in the Hardinsburg separates the belt sandstone body from a moderately thinned Haney Limestone. Of the smaller elongate sand bodies in the Hardinsburg, the pods are more abundant than are ribbons, particularly in association with belt sand bodies.

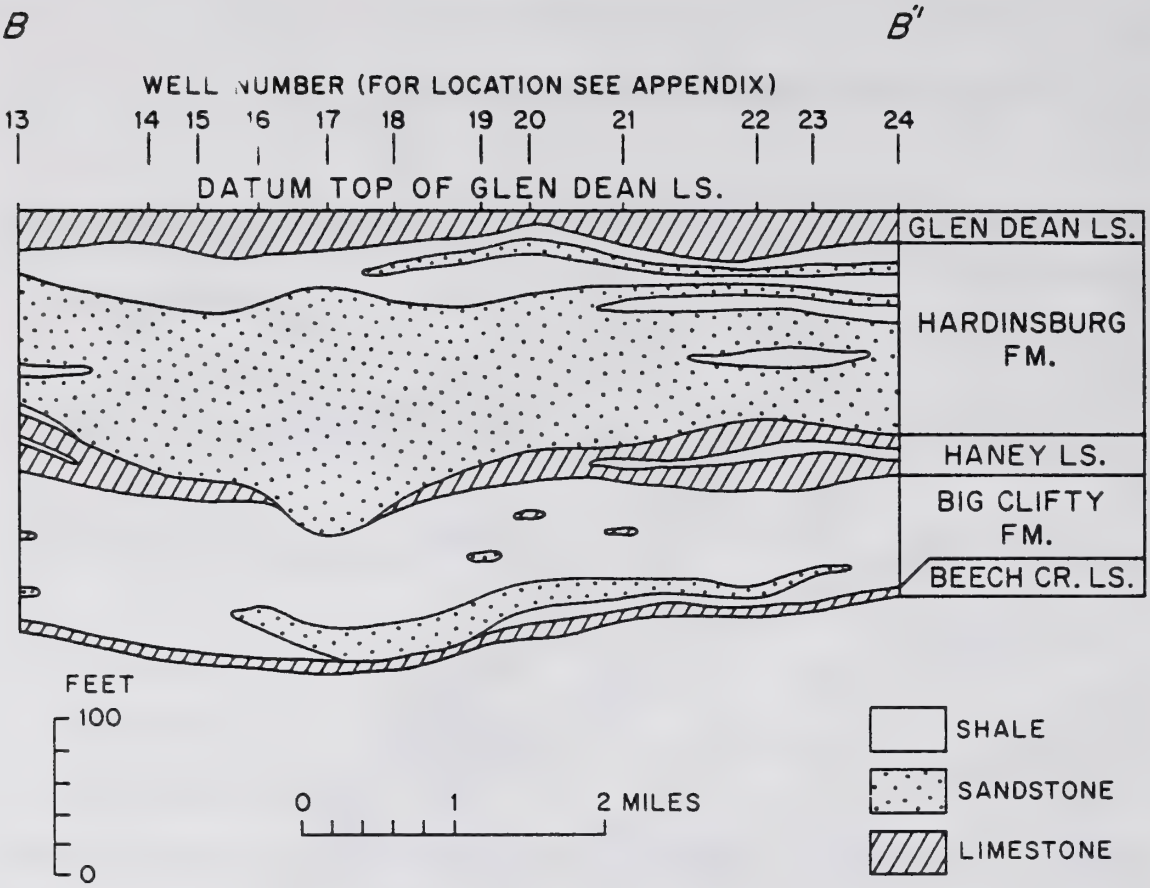

FIGURE 8. Cross section BB′. Location and other well information is given in Table 1.

Where very thick belt sandstones lie at its base, the lower contact of the Hardinsburg is a scoured surface of discontinuity. In the area of thinned Haney (Figure 4), the Hardinsburg belt sandstones lie in some places on the Big Clifty Formation. Away from the thick belt sandstones the contact between the Hardinsburg and Haney is conformable. The Hardinsburg is conformably overlain by the Glen Dean Limestone or unconformablly overlain by rocks of the Pennsylvanian System.

DISCUSSION

The belt sandstone bodies in the Hardinsburg have been variously interpreted as fluvial deposits filling channels previously cut by subaerial erosion, as fillings in channels eroded by marine processes, and as distributary sandstones associated with deltaic sedimentation (Swann, 1964). Whether deposited by fluvial or deltaic processes, favored interpretations commonly invoke regression of the sea and movement of the shoreline, frequently beyond the limits of the present Illinois Basin.

Not all geologists are satisfied with a model invoking extensive transgression and regression as the dominant influence on the alternation of siliciclastic and carbonate rocks of the Chesterian Series in the Illinois Basin. For example, Sullivan (1972) concluded that the massive sandstones that occupy much of the entire West Baden interval, in what he called the West Baden clastic belt, were deposited at the same time as the normal sandstone, shale, and limestone succession that

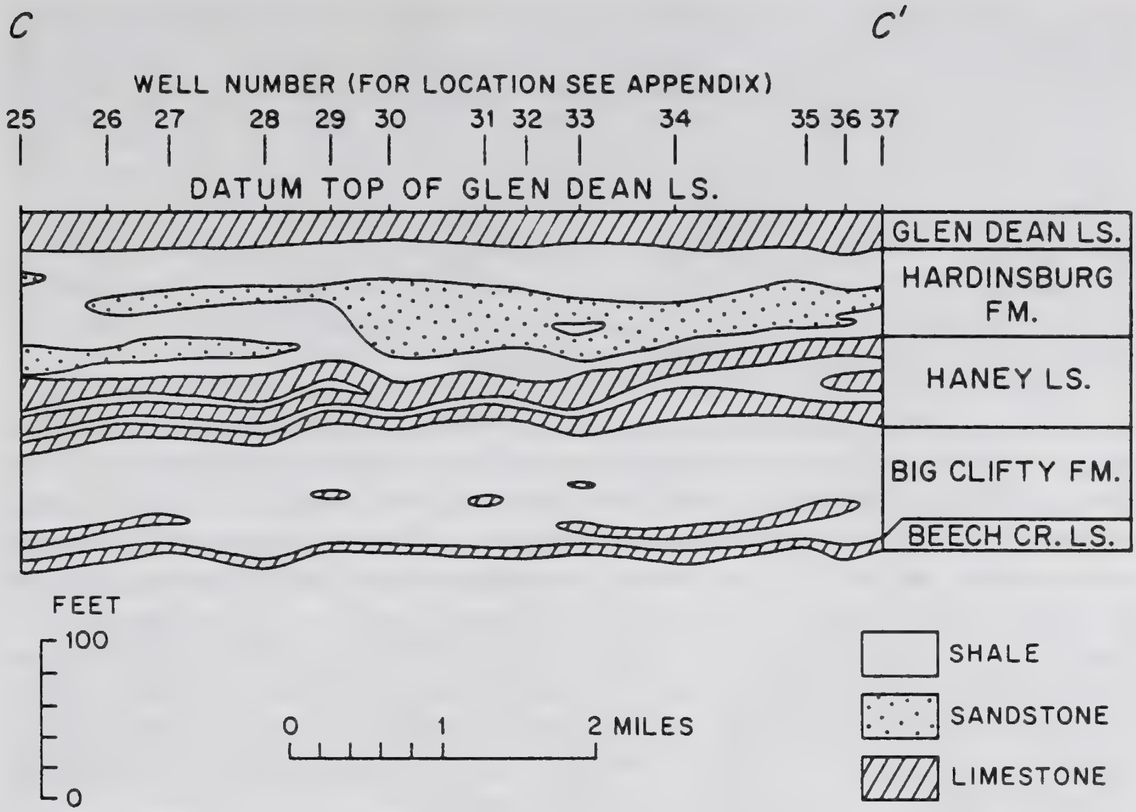

FIGURE 9. Cross section CC′. Location and other well information is given in Table 1.

accumulated outside of the clastic belt. In several places within the West Baden clastic belt, the contact of the basal sandstones with the underlying Paoli Limestone is a scoured surface of discontinuity (Droste and Carpenter, 1990). The western branch of the West Baden clastic belt has an orientation and location very similar to the belt sands in the overlying Hardinsburg Formation. Gray (1978) reported that he saw no convincing evidence that the rocks of the Buffalo Wallow Group, overlying the Hardinsburg, were deposited in non-marine environments. Droste and Keller (1989) agreed with Gray, and they suggested that the belt sandstones in the Tar Springs and Waltersburg Formations of the lower Buffalo Wallow Group were deposited in peritidal and shallow subtidal environments. The Tar Springs and Waltersburg belts of elongate sand bodies also have locations and orientations very similar to those of the Hardinsburg. Treworgy (1988) has reviewed those studies that interpret the Big Clifty Sandstone as tidally influenced. The ultimate test of the lateral equivalence of clastics and carbonates awaits a more finely divided biochronologic time scale than currently exists.

BELT SAND DEPOSITION

The interpretation that follows modifies and expands the depositional history presented for belt sandstones in the Tar Springs and Waltersburg Formations (Droste and Keller, in press) and in the Hardinsburg Formation (Laurin, 1988). For comparison with better known and more recent geological rhythms, we assume that the Chesterian Series was approximately 10 million years in duration (for example, see Shaver, *et al.*, 1985) and the interval of time during which the Hardinsburg rocks were deposited was several hundred thousand years. Following

Potter (1963, plate IG), we assume that the two areas of belt sandstone in the Hardinsburg have a common junction in Knox County, Indiana. They were deposited in very similar sedimentary environments during the same time interval and represent sand bodies in the "Hardinsburg delta" as shown by Potter (1963: 82, fig. 54). The factors affecting the preserved record mainly depend on 1) relationships between the tectonic events in the basin of deposition and in the surrounding source lands, 2) variation in climatic patterns, 3) minor variation in processes of sedimentation in the basin of deposition at the time the sediment accumulated permanently, and 4) post-depositional events that may destroy the evidence for and the scope of original deposition.

In Late Mississippian time, the Illinois Basic area was a gently subsiding cratonic embayment of a continental margin that lay several hundred kilometers to the southwest. Treworgy (1988) has described this setting as a tidally and tectonically influenced ramp. The area was a locus of deposition in shallow marine environments (Figure 3). Slow basinal subsidence rates made room both for the terrigenous load provided by slowly rising source lands and for carbonate sediments during times of lower siliciclastic input. Subtle basement movements associated with such features as the Wabash Valley Fault System, the LaSalle Anticlinal Belt, and the Rough Creek Lineament were operational and produced subdued topography on the sea floor. Former sea floor topography is inferred from units that thin over the former topographic highs.

A cyclical or rhythmic variation in the amount of rainfall associated with a changing climatic pattern, controlled at least in part by changes in storm tracking across the basin, produced times of both higher and lower terrigenous input to the basin. During times when storm tracts were either more common or more intense as they crossed the basin from the continental margin to the southwest toward the cratonic sources lands, heavy rainfall resulted and more mud and sand were delivered by streams to sites of deposition within the basin. During times when the storm paths were neither numerous nor intense, periods of lower rainfall in source areas resulted in reduced terrigenous input and carbonate sedimentation prevailed throughout the basin. The north river (Figure 3) clearly was the major supply route for the quartz sand in the belt sandstones of the Hardinsburg. Mud was delivered to the basin by the northeast and east rivers, but neither of these two systems carried a load rich in quartz sand. The north river became the major sand contributor because preferential northward storm tracking produced higher rainfall in northern sources, and northern sources probably contained more exposed quartz-rich sandstone. Inferentially, stream gradients differed little among these rivers because their headwaters were hundreds of kilometers to the north and east. The paleogeographic and tectonic setting as well as the mineralogy would seem to preclude arid conditions along the river courses in contrast to Swann's original proposal of arid-humid cycles.

General water depth was controlled principally by regional tectonics affecting the rate of source uplift and rate of basin subsidence, but shallow water environments prevailed. Sea floor lows, produced by a slightly greater rate of subsidence, became loci of strong current activity produced by storm surges, wind forcing, and tidal action. Based on the thickness of sandstone in the Hardinsburg Formation, the major area of local increased subsidence was a zone trending southward through Knox and Gibson Counties and southwestward from northern Vanderburgh through southeastern Posey County. In addition to the major area of thick belt sandstone, smaller areas of belt sand occur that are not as long or as wide as the major sand belt. For example, a distinct zone of belt sandstone trending southwestward in western Posey County is roughly parellel but separate from the major belt sand zone in northern Vanderburgh and southeastern Posey County. The margins of zones of belt sands are very irregular and range in width from less than 5 miles to more than 15 miles. Quartz sand was funneled into these areas and focused current activity produced much reworking. Where the currents were most concentrated, scouring of the sea floor was common. As long as the focused current activity prevailed and the quartz sand supply was maintained, belt sand bodies accumulated. The fining-upward texture and decrease in sorting in the belt sand bodies resulted when current funneling was reduced. Away from the areas of belt sand accumulation storm currents mobilized sand and local tidal currents produced pods and ribbon deposition above storm wave base. Post-depositional erosion prior to the onset of sedimentation in Pennsylvanian time has forever removed the evidence to document the full extent of the deposition that occurred in Late Mississippian time.

The Hardinsburg belt sandstones in the area between Knox County and southward into Kentucky began forming in Haney time. That is, the deposition of limestones in the Haney had not been completed before the onset on quartz sand deposition of the belt sand bodies in the Hardinsburg. Lows on the sea floor resulted because of an increase in subsidence rate locally. Early-formed Haney limestone beds may have been scoured, and belt sand bodies accumulated in areas where currents were focused. Carbonate deposition continued away from the area of concentrated currents. As the climate in the northern source area changed to produce greater rainfall, more and more terrigenous sand and mud were delivered to the basin, and eventually areas of carbonate deposition were smothered. Belt sand continued to accumulate until a climatic change resulting in less rainfall diminished the supply of terrigenous sediment. Finally, the terrigenous load was so reduced that carbonate deposition in clear, shallow water began in Glen Dean time.

A satisfactory modern analogue of the Illinois Basin, that is, a low latitude basin on a broad cratonic platform, apparently does not exist. The broadest platforms today are in temperate and higher latitudes, and low latitude shelves are in zones of active tectonism (southeast Asia). Perhaps the shelves of northern Australia provide the best modern models, but they are very poorly studied. The recent reports of the 3-dimensional distribution of sand bodies in the Amazon Deep-Sea Fan (Damuth, *et al.*, 1988; Manley and Flood, 1988) suggest that this might be a model for sand deposition as modified by conditions in much shallower water on a cratonic ramp. The modern Amazon Fan exhibits stacking of sand bodies, meanders, sand belts, and cyclicity, all of which are found in the Chesterian clastic intervals in the Illinois Basin. Not surprisingly, carbonates are lacking in this steep-slope, deep-water, modern analogue.

Alternations of transgressive and regressive seas through the late Mississippian (Chesterian) implies either a rhythmic rise and fall of sea level or a comparable tectonic rise and fall. Neither of these alternatives is at present appealing to us. Rhythmic tectonism has been widely postulated in this century, although inadequately explained as a process, and late Mississippian glaciations are too poorly dated and documented (Caputo and Crowell, 1985) to provide convincing evidence for the rhythmic rise and fall of late Mississippian sea levels. Nevertheless, Algeo and Wilkinson's (1988) analysis of Carboniferous sedimentary cycles suggests that these cycles are consistent with, but not proof of, Milankovitch orbital modulations mediated by Carboniferous glaciations. The resolution of Carboniferous chronologies is presently too coarse to independently test this model.

ACKNOWLEDGMENTS

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UNUSUAL RAVINE GEOMORPHOLOGY IN THE NORMAN UPLAND OF SOUTHERN INDIANA[1]

Henry H. Gray
Indiana Geological Survey
Bloomington, Indiana 47405

ABSTRACT: Unusual physical features of some of the ravines in the Norman Upland of southern Indiana help to confirm that stream entrenchment has been an important recent geomorphic event in this region. The most common and most intriguing of these features is offset drainage in minor ravines. Other features, all in major ravines, include parallel drainage, shallow entrenched meanders, concordant spur shoulders, and duplex profiles. In the larger valleys, however, the most recent event has been alluviation. These two processes are not in conflict but are simply different aspects of the most recent geomorphic cycle, which dates from Wisconsinan time to the Present.

INTRODUCTION AND PHYSIOGRAPHIC SETTING

In this paper, I will describe and interpret some minor features of the Norman Upland, a physiographic region in southern Indiana that is bounded on the east by the prominent Knobstone Escarpment, on the west by the karst areas of the Mitchell Plain, and on the north by the Wisconsinan glacial boundary, which here marks the south edge of the Tipton till Plain (Figure 1). This physiographic region has no precise counterpart elsewhere, but in Kentucky a similar region is divided into areas known as the Knobs, Muldraugh Hill or the Muldraugh Escarpment, and part of the large area called the Mississippian Plateaus.

Rocks that underlie the Norman Upland and that determine its distinctive topography belong to the Borden Group, a series of shales and siltstones of Mississippian age that are variably resistant to erosion but that include few prominent resistant beds. Hills of the Norman Upland are therefore characterized by relatively smooth (and relatively steep) slopes. Rimrocks and ledges are not common, and natural outcrops are not abundant.

Subdivisions of the Norman Upland. In that part of the Norman Upland that lies north of the East Fork of White River (Figure 1), three major subdivisions may be recognized. Along the east edge, a narrow belt of eastward-facing hills, drained to the east by short, steep streams, is the Knobstone Escarpment. The broader part of the upland, a maturely dissected plateau, occupies most of Brown County and parts of adjacent counties. This area, the classic Norman Upland of Malott (1922), drains westward, down the regional slope of the underlying strata, by way of large integrated stream networks such as that of Salt Creek. North of the valley of Beanblossom Creek, along the north edge of the upland, the dissected plateau has been affected in a limited way by the pre-Wisconsinan glaciations,

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[1] Publication authorized by the State Geologist, Indiana Geological Survey.

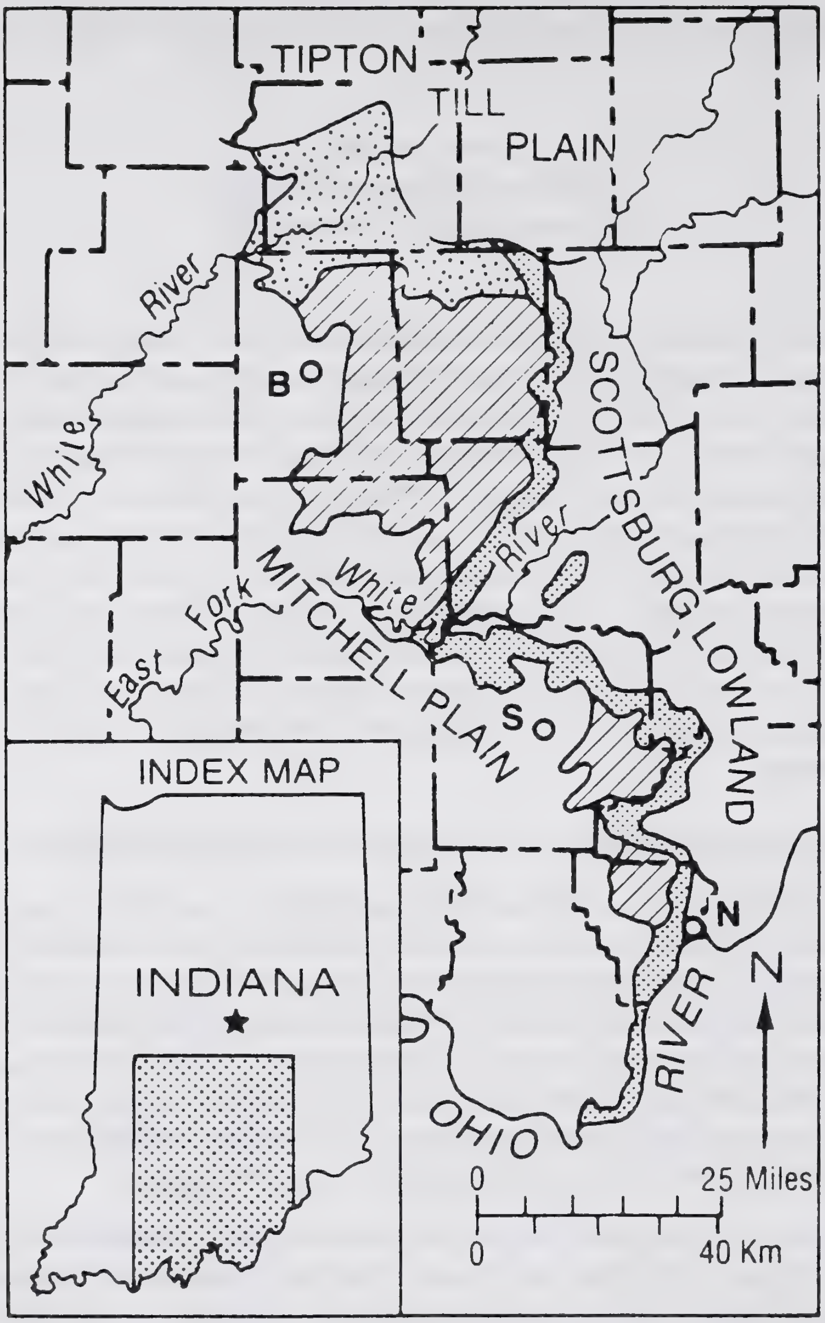

FIGURE 1. Map of south-central Indiana showing the Norman Upland and its subdivisions: Knobstone Escarpment (shaded), classic plateau area (diagonally ruled), and glacially modified area (stippled). B, Bloomington; S, Salem; N, New Albany.

and from that area northward repeated glaciation has subdued and obscured both the Knobstone Escarpment and the upland.

South of the East Fork of White River, the escarpment belt is somewhat broader and more complex. In part, this is because the escarpment incorporates some anomalous drainage features that may have originated marginal to one or another of the pre-Wisconsinan ice sheets; Muddy Fork of Silver Creek, treated as a simple instance of piracy by Malott (1922, pp. 180-186), is an example. The plateau consists only of small isolated tracts and does not exist at all south of

New Albany. There the entire width of the Norman Upland is taken up by the Knobstone Escarpment, which narrows sharply southward where the Ohio River impinges at its base.

Classification of valleys and ravines in the Norman Upland. It is convenient for purposes of this discussion to classify the valley types observed in the Norman Upland. I will refer to the valleys as **primary**, if they are occupied by through-flowing streams, such as the East Fork of White River, and **secondary**, if they are occupied by lesser streams but nevertheless have broad and active alluvial valley floors. The valleys of Salt Creek and Beanblossom Creek are secondary valleys.

Ravines are smaller, shorter, and steeper; those I classify as **major** ravines have narrow, inactive alluvial floors. Ravines designated **minor** are very steep, commonly have bedrock floors, and serve primarily to dissect the hillslopes. Minor ravines are not well delineated on the U.S. Geological Survey 7½-minute topographic maps, but the best of these maps do illustrate the greater density of minor ravines where the underlying strata are more clayey and shale-like than elsewhere.

Note that I have not classified these features in terms of perennial versus seasonal streams; nearly all streams in the Norman Upland except those that are through-flowing and those that have controlled flow, are seasonal.

RAVINE FEATURES

Several kinds of unusual minor drainage features occur widely in the Norman Upland. Overall, these features indicate that in the Norman Upland there were earlier erosion cycles that had higher baselevels than the present one—a conclusion that is neither original nor surprising but that receives independent confirmation here. Most of these features have no counterpart in the other upland regions of southern Indiana.

Offset drainage in minor ravines. Most of the minor ravines in the Norman Upland are what Stockdale (1931, p. 49 and Fig. 4) called flume ravines. These incise the hillslopes only slightly, trend directly downslope, and are steep. Branching is uncommon, and the bedrock floor is trough-like, a result of the spalling or sheety weathering that characterizes the Borden rocks.

Some minor ravines, however, trend downslope in their upper courses but make a right-angle turn in mid-course to trend nearly parallel to the slope and to join other minor ravines before turning downslope again, through a small but sharp gap, to enter a major ravine or other larger valley (Figs. 2, 3, 4). Thus, they tend to form a rudimentary trellis drainage system. I will refer to this type of drainage as offset.

In many ravines of this type, it appears that the initial cross-slope diversion may have taken place at the upper edge of a colluvial apron that collected at the toeslope when the base level of the stream system was somewhat higher than it is today, and that later they were entrenched into the underlying bedrock and etched into their present configuration. Joint control is also possible; Borden rocks commonly develop joints parallel to the hillslopes, probably as a response to erosional unloading. The direction of the offset seems to conform to no regional pattern, but many of the toeslope ridges, now isolated from the mainslope by the lateral segment of the offset ravine, correlate in height with terrace remnants and other features nearby that signify the position of the former higher base level.

Ravines of this type apparently have not been commented on before, and there is no hint of them on the U.S. Geological Survey $7^1/_2$-minute topographic maps (Figs. 2, 3). In part, this may be because these features are small and the tree cover obscures them; they are, in fact, particularly difficult to observe in summer. Although they occur throughout the Norman Upland, they are more common on the steeper northward-facing slopes than on the gentler southward- and southeastward-facing ones.

Parallel drainage in major ravines. Ravines designated as major have narrow, inactive valley floors. In some of the wider ravines, tributaries from opposite sides do not join but form two channels, one along each side of the ravine. Where the streams have become entrenched, a mid-ravine ridge is quite prominent. In the examples illustrated (Fig. 5), the height of the mid-ravine ridge is accordant with benches and terraces that define a prior drainage level in adjacent parts of the drainage system. Parallel drainage is less common than the offset drainage described above.

Entrenched meanders in major ravines. In a few places, where valley floors are wide enough, small meander sets are lightly entrenched into the stony alluvium of major ravines (Fig. 6a). A lessened slope and broadened valley floor probably favor the development of these meanders.

Only a few such features are shown on the U.S. Geological Survey $7^1/_2$-minute topographic maps; a few more, mostly smaller scale, examples can be identified on aerial photographs and in the field. The feature illustrated shows that these are truly entrenched meanders, not merely diversions resulting from accumulations of colluvium or the building of alluvial fans at the mouths of minor ravines, both of which are common.

Concordant spur shoulders in major ravines. In a few major ravines, the rounded interfluves between tributary minor ravines are truncated sufficiently sharply to suggest that in the most recent cycle of erosion, the major ravine has become entrenched, and the minor ravines have been steepened (Figs. 6b, 7). Here, one may readily visualize a deeper and steeper profile associated with the present level of the ravine and a higher and gentler profile associated with an earlier drainage level. This "two-layer" topography is common throughout the Norman Upland but is best expressed where a set of concordant spur shoulders can be recognized.

This simple interpretation cannot be applied, however, to the large faceted spurs that are common in the secondary valleys. All secondary valleys in the Norman Upland have been repeatedly entrenched and partly refilled; lateral stream activity during any part of this complex history can produce spectacular spur truncations (Fig. 8) that in themselves probably have little regional geomorphic meaning.

Duplex profiles in major ravines. In a few major ravines, isolated small tracts of stony alluvium in upper parts of the ravines are separated from alluvial areas in lower parts of the ravines by a low knickpoint and a ravine segment in which no alluvium is mappable. These knickpoints can be obvious in the field but are not reliably shown on aerial photographs or on topographic maps, and although

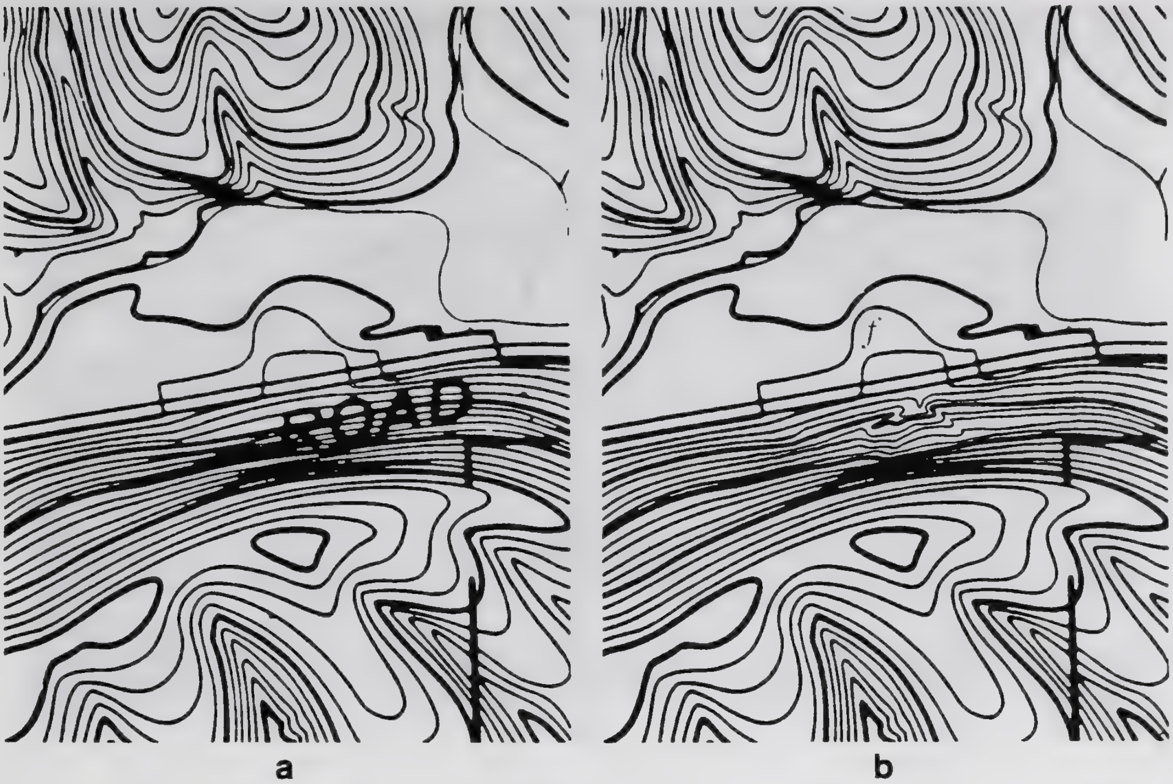

FIGURE 2. Maps showing offset drainage in a minor ravine tributary to Kerr Creek, Monroe County (Sec 32, T9N, R1E): (a) as shown on U.S. Geological Survey $7^1/_2$-minute Unionville Quadrangle (enlarged 3x); and (b) as modified on the basis of field observations. An alluvial fan (*f*) is at the mouth of the ravine.

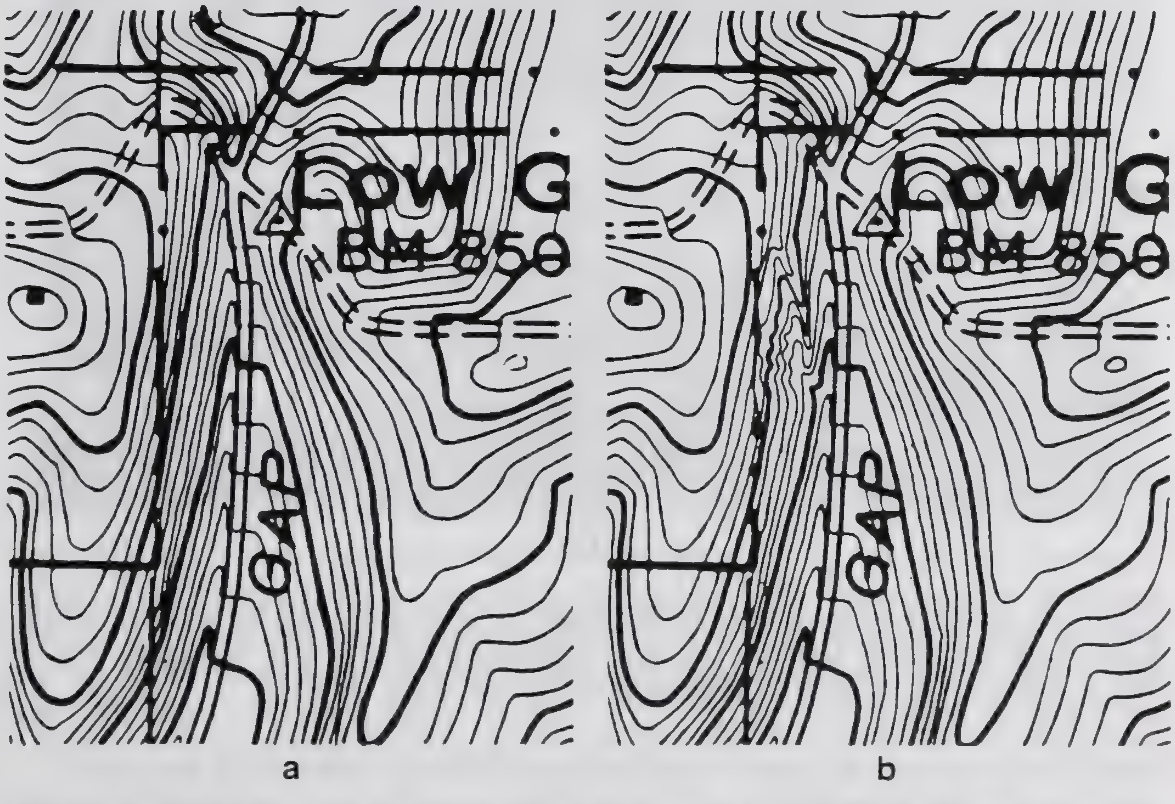

FIGURE 3. Maps showing multiple offset drainage in Low Gap, Monroe County (Sec 11, T10N, R1E): (a) as shown on U.S. Geological Survey $7^1/_2$ Hindustan Quadrangle (enlarged 3x); and (b) as modified on the basis of field observations.

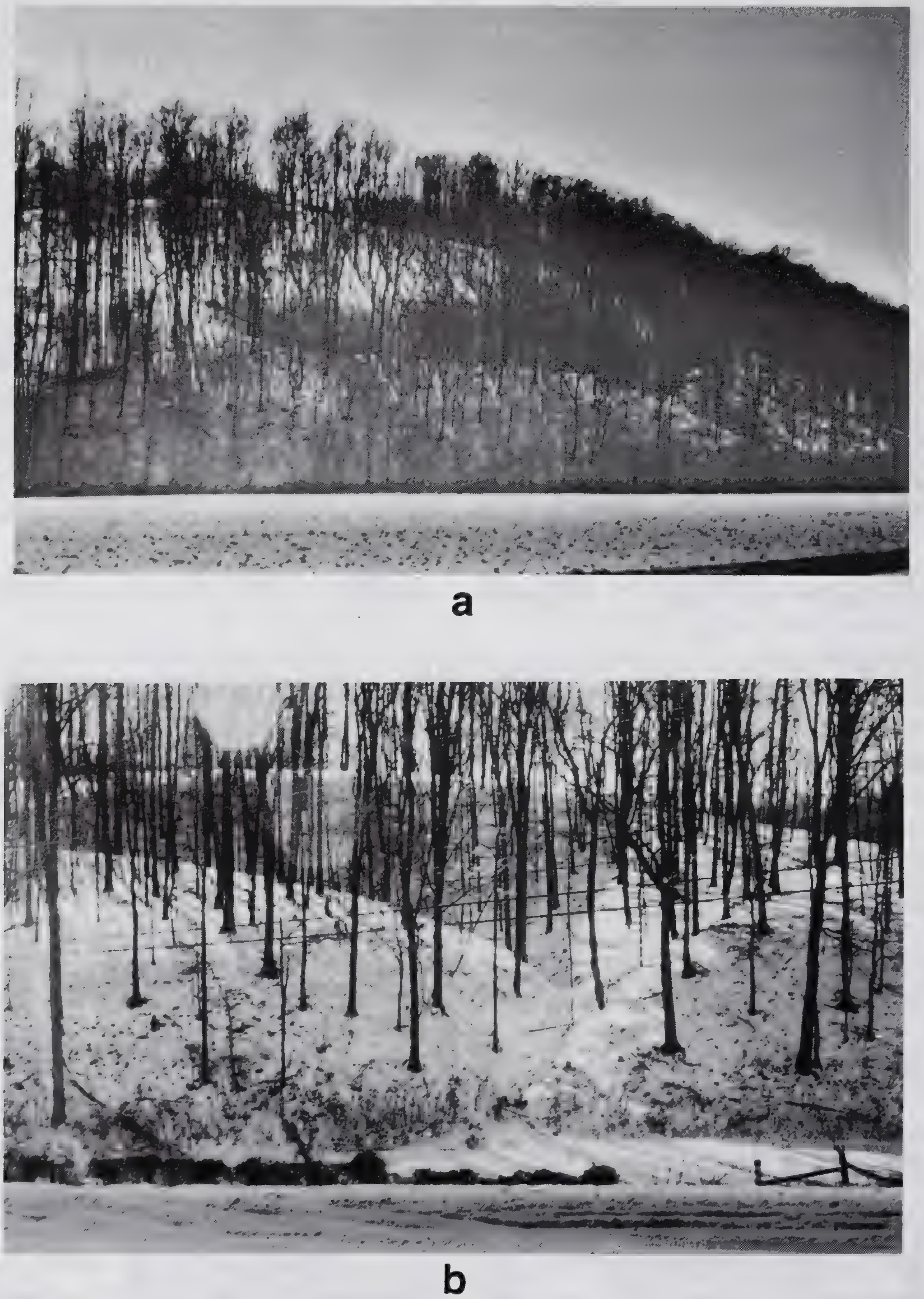

FIGURE 4. Photographs showing offset drainage in minor ravines: (a) near Gnawbone, Brown County (SW1/4, SW1/4, Sec 19, T9N, R4E); and (b) upper end of Henderson Creek, Brown County (NW1/4, Sec 28, T9N, R4E).

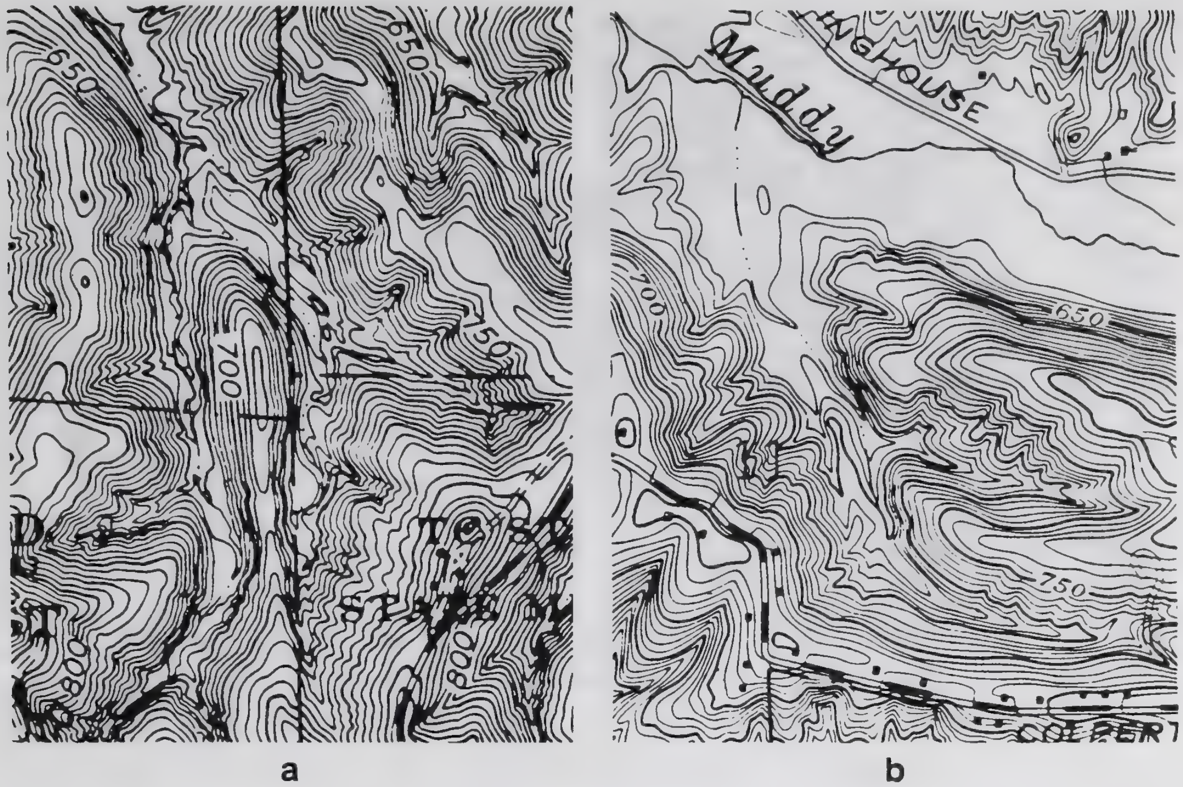

FIGURE 5. Maps showing parallel drainage in major ravines: (a) near T.C. Steele State Memorial, Brown County (Secs 12 and 13, T8N, R1E; and Secs 7 and 18, T8N, R2E), as shown on U.S. Geological Survey 7½-minute Belmont Quadrangle (enlarged 1.5x); and (b) tributary to Muddy Fork, Monroe County (Sec 11, T9N, R1W), as shown on U.S. Geological Survey 7½-minute Unionville Quadrangle (enlarged 1.5x). Note accordance of the crests of the mid-valley ridges with terrace and bench levels in adjacent streams and with valley-floor levels upstream.

they surely indicate a lowering of baselevel, they probably have no regional significance, because they do not correlate from one ravine to another. Furthermore, some ravines have more than one knickpoint.

Distribution of alluvial soils in major ravines. The typical valley-floor soil series in the stony alluvium of major ravines is the Burnside. Although Burnside soils are entisols and lack true argillic horizons, they do have recognizable and somewhat complex B-horizonation. This, along with their history of infrequent flooding, suggests that Burnside soils are relicts or near-relicts and that alluvial accretion on these areas now is very slow. In contrast, soils characteristic of the secondary valleys, such as those of the Haymond and Wakeland series, lack B-horizonation altogether and historically have been flooded frequently. These properties imply relatively rapid alluvial accretion, an important part of which may relate to deforestation and other land-use changes of the past two centuries.

Burnside soils occur typically in elongate to irregular tracts that at their downvalley ends merge with larger areas of the more active alluvial soils, commonly at or not far below the transition from major ravine to secondary valley.

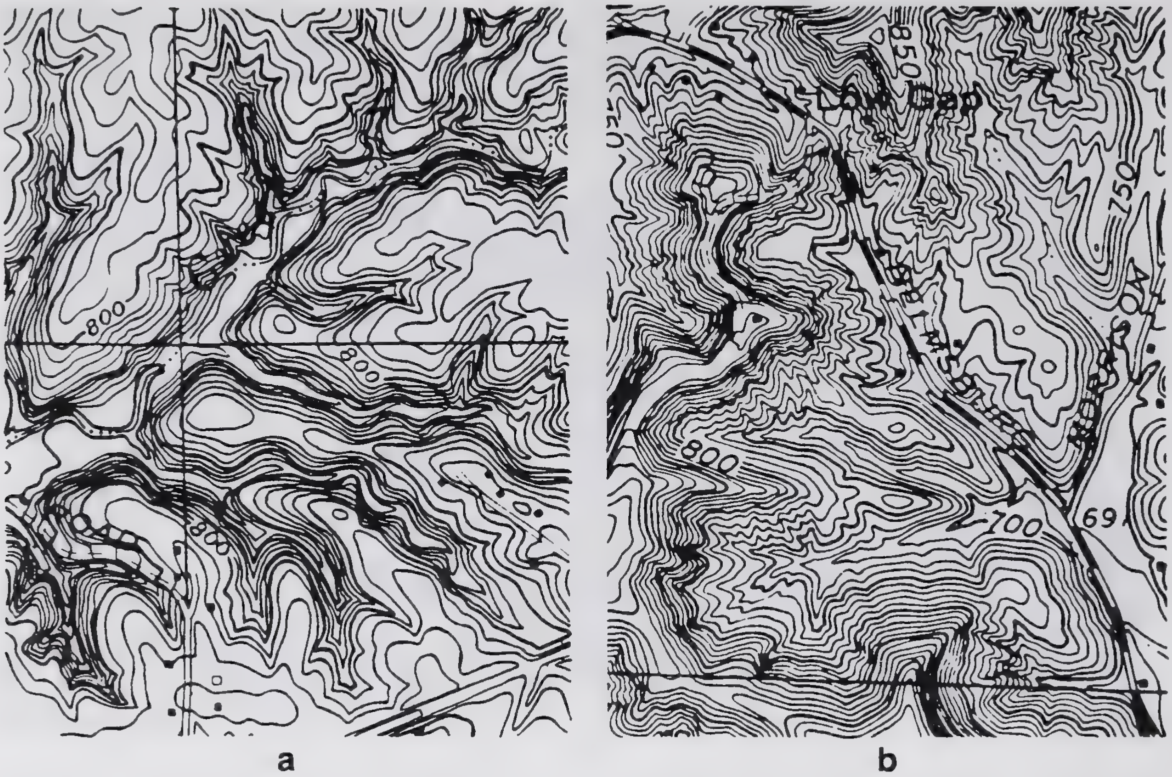

FIGURE 6. Maps showing: (a) entrenched meanders in alluvium in a major ravine, upper Griffy Creek, Monroe County (Secs 13, 14, 23, and 24, T9N, R1W), as shown on U.S. Geological Survey 7$^1/_2$-minute Unionville Quadrangle (enlarged 1.5x); and (b) concordant minor spur shoulders (see also Figure 7) along major ravines that head at Low Gap, Brown County (Secs 3 and 10, T9N, R2E), as shown on U.S. Geological Survey 7$^1/_2$ Belmont Quadrangle (enlarged 1.5x).

They also occur in isolated patches in upper parts of major ravines, typically above a knickpoint and in areas where the ravines widen just a bit. The alluvial deposits in which Burnside soils are formed are increasingly stony downward and appear to represent a geologic episode when erosion was much more active than it is today.

Two possible scenarios may be suggested for these deposits: (1) a rigorous periglacial climate *per se* or (2) geomorphic stresses related to rapid and possibly repeated climatic change from moderate to periglacial and back to moderate climate. In either scenario, the implication is that these coarse alluvial deposits date for the most part from Wisconsinan time.

GEOMORPHIC IMPLICATIONS AND DISCUSSION

Common among the features described above is the indication that the most recent geomorphic process to affect the ravines in this region has been entrenchment. Recent entrenchment is confirmed by other features observed in the secondary valleys. The valleys of Salt Creek and its major tributaries, for example, contain two sets of terrace remnants that stand a few feet above the present valley floor (Gray, 1989). Underlying the higher of these terraces is sandy outwash that is pre-Wisconsinan in age, as indicated by a thick paleosol atop the sand and a

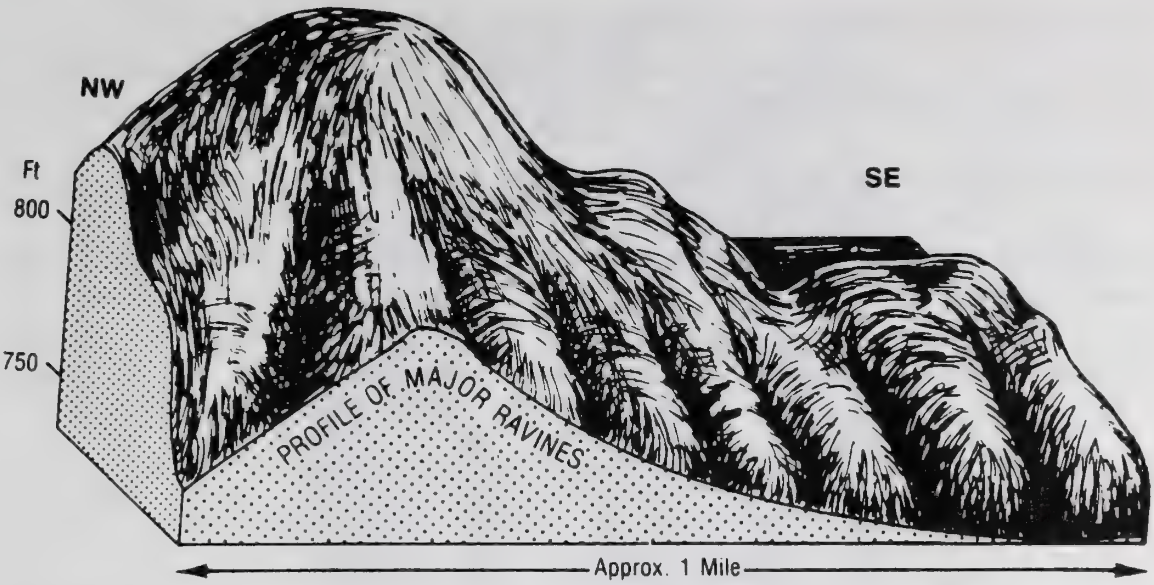

FIGURE 7. Block diagram through Low Gap, Brown County, showing concordant minor spur shoulders along major ravines. See also Figure 6b.

thick mantle of loessial silt that caps the paleosol. The lower terrace lacks the outwash and consists principally of silt, and because it contains no well-developed paleosol, it probably is Wisconsinan in age.

The outwash terrace is lacking in secondary valleys south of the East Fork of White River, but a terrace corresponding to the lower one on Salt Creek is present. Other evidence of recent regional lowering of base level includes abandoned meander loops at several levels that are scattered along many of the primary and secondary valleys of southern Indiana (Gray, 1989). Deposits in these valleys, however, show that entrenchment has not been the most recent geomorphic process to affect them. The broad floors of the primary valleys are underlain by alluvium and thick outwash deposits; the floors of secondary valleys are underlain by fine-grained slackwater and alluvial deposits that thicken downvalley (Gray, 1971). Clearly, in these valleys the most recent major geomorphic event has been active valley filling. Most of these deposits are Wisconsinan to Holocene in age (Gray, 1974), and soils of the valley floors confirm that this process is continuing.

At least two hypotheses may be presented to explain this seeming paradox. First, one might suggest that the slackwater deposits and silty alluvium occupy the valley system up as far as the backwater curve would indicate and that the upper reaches of the system are as yet unaltered from a previous stage of entrenchment. This would imply that the junction between the lower and upper parts of the system might be abrupt, but this in fact is not so. The lower valley deposits merge rather gently with the upper valley deposits; that is, the junction between active alluvial areas and inactive alluvial areas is irregular, diffuse, and generally unclear, although in most places it is somewhere in the upper ends of the secondary valleys and below the mouths of the major ravines. This hypothesis would also imply that the upland area and all the tributary valley network is an inactive relic. If this were so, deep paleosols should be widespread, but in fact they are not. Therefore, I can set this hypothesis aside, at least provisionally.

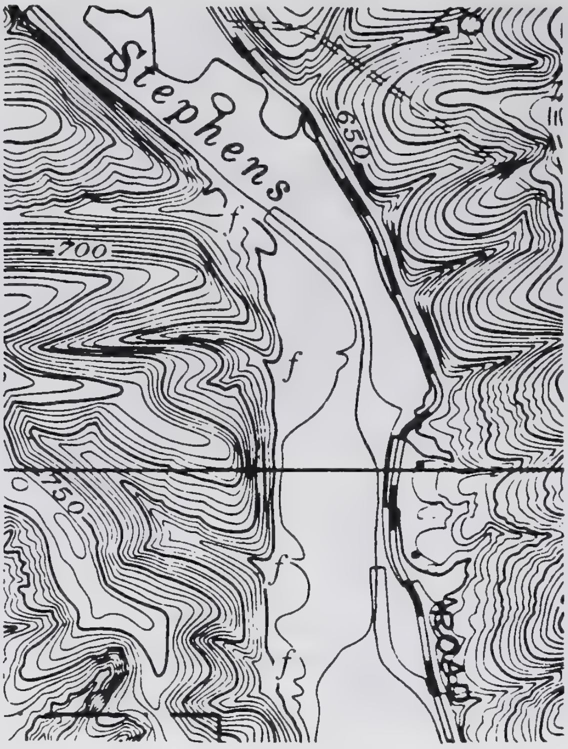

FIGURE 8. Map showing large facets on spurs adjacent to Stephens Creek, Monroe County (Secs 28 and 33, T9N, R1E), as shown on U.S. Geological Survey 7½-minute Unionville Quadrangle (enlarged 1.5x). Except that these spurs predate the alluvial fans (*f*), they probably have no regional significance.

A second hypothesis suggests that the gradient of the typical valley system in the Norman Upland is poised on a sort of teeter-totter. As the lower part of the system is being alluviated, the upper tributary network is still being entrenched. The diffuse boundary between these activities is the fulcrum of the teeter-totter, a sort of alluvially neutral zone, and the entrenchment recorded by the ravines of the Norman Upland as the latest geomorphic event to affect them probably is mostly coeval with the latest episode of valley filling in the lower parts of the secondary valleys. This process couple apparently dates from Wisconsinan to Holocene.

I favor this second hypothesis as being more consistent with the facts presently on hand. It is also consistent with the concept that geomorphic systems are dynamic and include zones of erosion, transportation, and deposition that shift with changes in regional conditions. As Schumm (1973, p. 300) concisely put it, "the components of a geomorphic system need not be in phase."

A corollary conclusion is that the minor geomorphic features observed here are best understood in a broader context that includes the more complete history recorded in the valley fill of the secondary valleys. Thus, even in regions as uncomplicated as the Norman Upland, geomorphic elements such as hillslope evolution and stream processes should not be studied in isolation, but in concert.

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TEMPERATURE ANOMALIES DURING THE DROUGHT OF 1988: HIGH DAILY RANGES THROUGH EARLY SUMMER IN INDIANAPOLIS, INDIANA

Thomas B. Williams
Department of Geography
Western Illinois University
Macomb, Illinois 61455
and
Sherman N. Shewmaker
Defense Mapping Agency
3200 South Second Street
St. Louis, Missouri 63118

INTRODUCTION

The early part of summer 1988 was characterized by a severe drought which affected a large area of the United States, extending from the Northern Plains across the Midwest and Ohio Valley and down into the Southeast. By mid-July, severe-to-extreme drought covered nearly 45% of the country, making 1988 the third worst in terms of geographic area affected in the twentieth century (Heim, 1988). Between late April and early July, a steady succession of cloudless days prevailed, bringing high temperatures and little rainfall (National Oceanographic and Atmospheric Administration/U.S. Department of Agriculture Joint Agricultural Weather Facility, 1988). The recurrent weather pattern not only produced widespread drought and growing deficits in precipitation, but also generated increasingly abnormal high diurnal ranges in temperature.

Several important factors contributed to the extreme dryness: 1) a lack of moisture in the air; 2) the absence of rain-producing mechanisms; and 3) the persistent nature of the weather pattern once it was established (Ludlum, 1988a,b). Warm, humid air masses normally begin to move northward in the spring and summer, spreading Gulf moisture through the Plains and Upper Midwest. Under the influence of high pressure, both at the surface and aloft, the supply of moisture was cut off. Upper air patterns were controlled by a ridge of high pressure centered over the midwestern U.S. (Ludlum, 1988a; National Oceanic and Atmospheric Administration National Weather Service Climatic Analysis Center, 1988), which displaced the storm track well to the north of its normal position. Cyclonic storms were diverted into Canada (Ludlum, 1988b; Martell, 1988); frontal passages occurred only infrequently (Ludlum, 1988a). Beneath the ridge, stable, warm, dry air masses dominated. The resultant clear skies, low humidity (dry air), and light winds prevailed day after day. Maximum insolation was received; high temperatures and sparse rainfall were the rule over an extensive geographic area (Ludlum, 1988b).

Weather conditions favorable to a low daily range of temperature were largely absent during the early part of the summer. Cloudy skies, high humidity, strong winds, and wet weather, which often accompany low pressure patterns and frontal systems, lower daytime temperatures but cause nights to remain warm. The resultant daily range of temperature is reduced considerably. Clouds are most

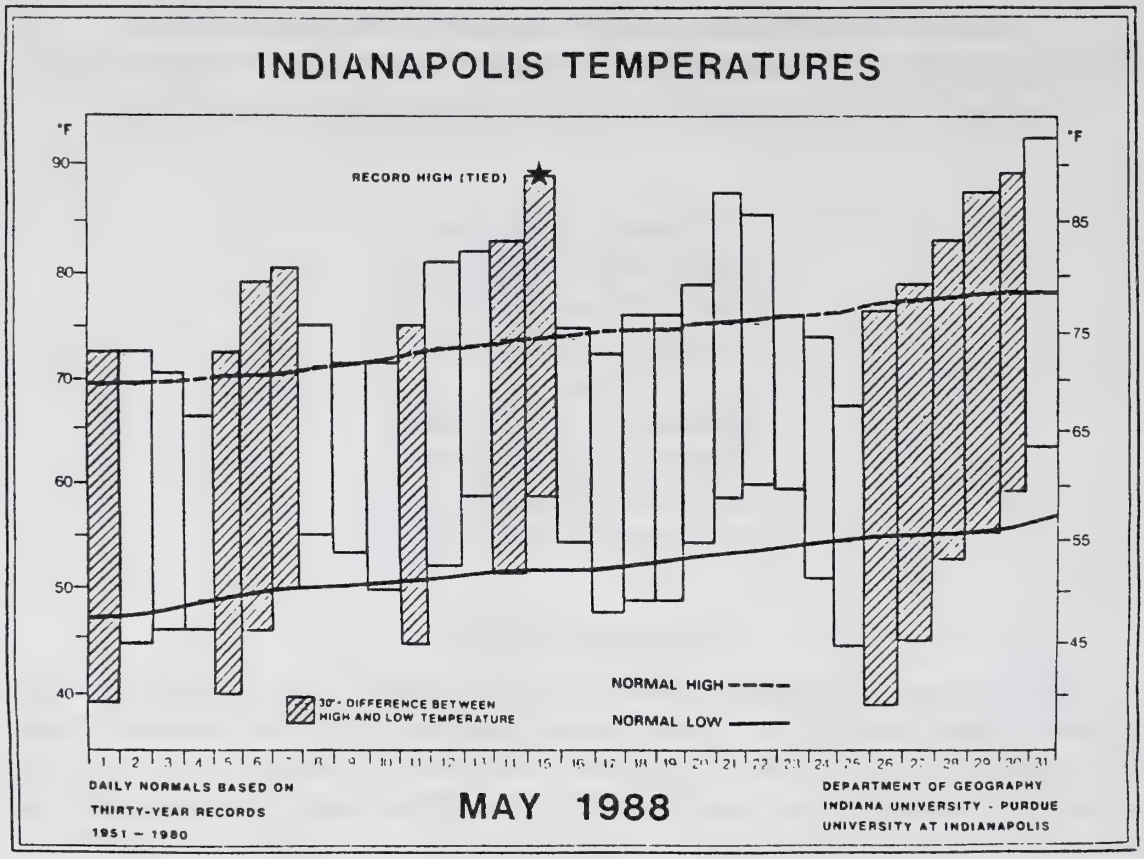

FIGURE 1. Daily maximum and minimum temperatures recorded at the Indianapolis airport for May 1988. Normal high and low temperatures are also shown. Days on which the daily temperature range was 30.0°F (16.7°F) or greater are shaded.

important, because they block incoming solar radiation (short-wave) and reduce heating during the day (Lutgens and Tarbuck, 1988). A higher percentage of the available radiant energy is diverted toward evaporation (latent heat) instead of warming the air (sensible heat). At night, outgoing terrestrial radiation (long-wave) from the surface is absorbed by moisture (i.e., clouds and humidity) in the air (Ahrens, 1988). Radiational cooling is slowed considerably. Winds play a dual role by mixing the air, which prevents rapid surface cooling, and by advecting warmer air into the area (associated with southerly flow).

Clear skies, dry air, light winds, and fair weather under the influence of high pressure produce a widespread difference between daily high and low temperatures. Abundant insolation causes rapid heating during the day. Evaporation is greatly reduced by extreme dryness, as a higher percentage of the sun's energy is used for surface and sensible heating, which increases both daytime warming and resulting air temperatures (Ahrens, 1988). At night, the lack of cloud cover and moisture in the air permits rapid radiational cooling and allows temperatures to cool considerably overnight without any mixing by winds. Larger diurnal temperature ranges are the product of warmer days in conjunction with cooler nights.

In this study, the anomalously high diurnal temperature ranges which occurred in Indianapolis, Indiana during an extended stretch of hot, dry weather through the early summer 1988 are described. The paper will detail the relation-

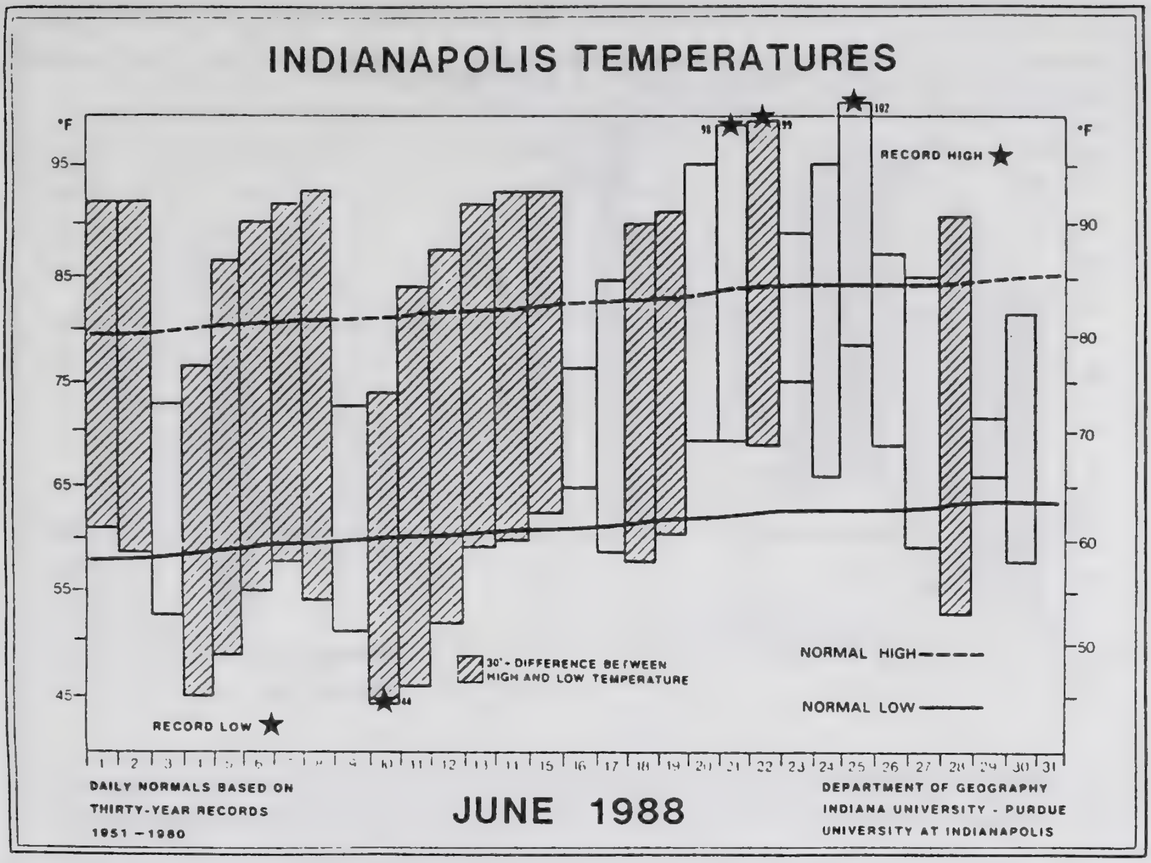

FIGURE 2. Climatic conditions for June 1988 (see Fig. 1 for explanation).

ships between the persistent weather pattern and associated parameters and the ensuing severe drought and widespread day-night variations in temperature. The recurrent conditions which characterized the drought period will be compared with climatic normals (1951-1980) and to values from the preceding two years (1986-1987) from May, June, and the first 10 days in July.

METHODS

Daily maximum and minimum temperatures, along with related weather conditions, were obtained from the National Weather Service forecast office at the Indianapolis airport. For comparative purposes, records from May, June, and early July 1986 and 1987 were used in addition to the current year (National Oceanic and Atmospheric Administration National Climatic Data Center, 1986, 1987, 1988). Climatic normals of temperature and precipitation for the same period are based on 30-year records from 1951-1980 (National Oceanic and Atmospheric Administration National Climatic Data Center, 1982).

Daily temperature ranges were determined from daily maximum and minimum values recorded in May, June, and the first 10 days in July. Cumulative totals and monthly averages were calculated for 1986, 1987, and 1988; the results were compared between years as well as to climatic normals. The data were also examined in relationship to associated weather conditions, such as average daily maximum and minimum temperatures, average monthly dew point, monthly precipitation, and percent possible sunshine.

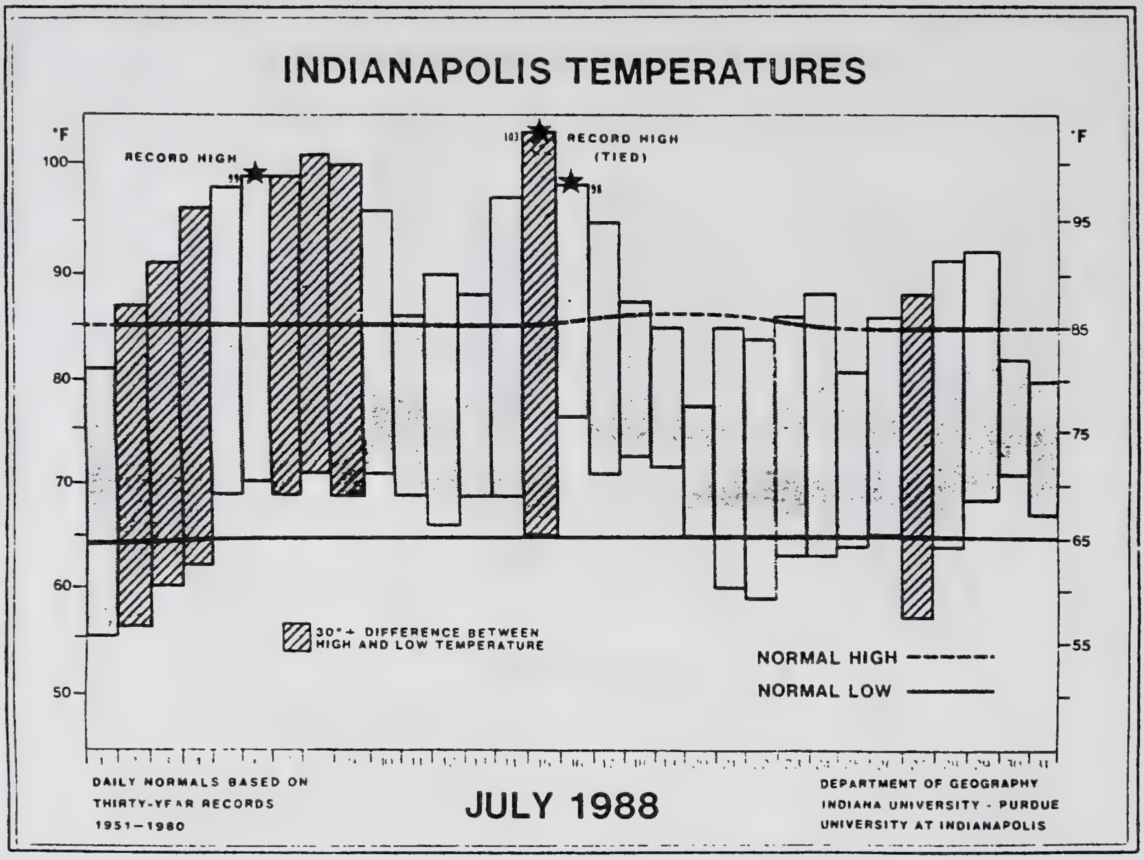

FIGURE 3. Climatic conditions for July 1988 (see Fig. 1 for explanation).

TABLE 1. Indianapolis weather conditions for May.

	May 1988	May 1987	May 1986	Normal
Average Daily Maximum	78.1°F	80.4°F	72.9°F	73.4°F
Average Daily Minimum	50.6	55.8	54.0	51.5
Average Daily Mean	64.4	68.1	63.5	62.5
departure from normal	+1.9	+5.6	+1.0	—
Average Daily Range	27.5	24.5	18.9	21.9
departure from normal	+5.6	+2.6	−3.0	—
Average Dew Point	46.0	53.9	53.6	—
Monthly Precipitation	1.06″	1.77″	7.37″	3.66″
departure from normal	−2.60″	−1.89″	+3.71″	—
Percent Possible Sunshine	73%	74%	56%	60%
clear days	12	11	5	7
partly cloudy days	11	12	5	9
cloudy days	8	8	21	15

RESULTS

Daily temperature range. Daily maximum and minimum temperatures recorded at the Indianapolis airport are shown for May, June, and July 1988

TABLE 2. Indianapolis weather conditions for June.

	June 1988	June 1987	June 1986	Normal
Average Daily Maximum	87.6°F	84.8°F	82.6°F	82.3°F
Average Daily Minimum	59.2	62.5	63.0	60.9
Average Daily Mean	73.4	73.7	72.8	71.6
departure from normal	+1.8	+2.1	+1.2	—
Average Daily Range	28.4	22.3	19.6	21.4
departure from normal	+7.0	+0.9	−1.8	—
Average Dew Point	50.7	61.8	62.5	—
Monthly Precipitation	0.36″	4.11″	3.58″	3.99″
departure from normal	−3.63″	−0.12″	+0.41″	—
Percent Possible Sunshine	81%	65%	62%	66%
clear days	14	10	6	7
partly cloudy days	12	4	8	11
cloudy days	4	16	16	12

(Figures 1-3). The widespread difference between daily high and low temperatures is immediately evident. The remarkable consistency of the graphs is indicative of the persistent weather pattern which produced both the extremely dry weather and the unusually large daily ranges of temperature. Days on which the daily range was 30.0°F (16.7°C) or higher are shaded on the graphs. There were 12 days in May with a range of 30.0°F (16.7°C) or more, with a maximum 38.0°F (21.1°C) range recorded on the 26th (Figure 1). More than half the days in June (17) experienced ranges of 30.0°F (16.7°C) or above, including a maximum difference of 39.0°F (21.7°C) on the 8th (Figure 2). The two days in June having the lowest daily ranges, 11.9°F (6.1°C) on the 16th and 6.0°F (3.3°C) on the 29th, were the two cloudiest days in the month, and two of the four days which received small amounts of rain. Only eight days in July recorded daily ranges of 30.0°F (16.7°C) or above, but six of these came during the first 10 days of the month (Figure 3). An abrupt change to a cloudy, humid, rainy weather regime occurred on July 10, which greatly reduced the diurnal ranges of temperature for the rest of the month. The onset of the new pattern is clearly depicted on the graph.

In May, the average daily range of 27.5°F (15.3°C) was 5.6°F (3.1°C) above normal, 25% greater than average. Daily ranges in June increased 33% from normal, averaging 28.4°F (15.8°C) or 7.0°F (3.9°C) above the norm. For the first part of July, a 46% increase above the normal daily range occurred in the 10-day period; the average diurnal spread was 9.3°F (5.2°C) higher than expected.

Five of the ten weeks from May 1 to July 9 experienced daily ranges in temperature which averaged more than 28.8°F (16.0°C), including the week of June 5-11, when the average daily range reached 33.9°F (18.8°C), and July 3-9 with a 30.6°F (17.0°C) average (data not shown). Over a three-week stretch from May 29 through June 18, the average daily temperature range exceeded 30.0°F (16.7°C) in each week (Figures 1 and 2).

Comparative weather conditions for May. The highest average daily range was in May 1988, 5.6°F (3.1°C) above the normal of 21.9°F (12.2°C). Daily

TABLE 3. Comparative conditions during July 1988.

	July 1988 all month	July 1-10 1st 10 days	July 11-31 last 21 days
Average Daily Maximum	90.5°F	94.8°F	88.5°F
Average Daily Minimum	66.1	65.2	66.5
Average Daily Mean	78.3	80.0	77.5
departure from normal	+3.2	+4.9	+2.4
Average Daily Range	24.4	29.6	22.0
departure from normal	+4.1	+9.3	−1.7
Average Dew Point	62.5	54.0	66.5
Monthly Precipitation	4.71″	0.04″	4.67″
departure from normal	−0.39″	−1.38″	+1.77
Percent Possible Sunshine	66%	80%	59%
clear days	10	4	6
partly cloudy days	9	4	5
cloudy days	12	2	10

maximum values were 4.7°F (2.6°C) **above** normal while daily minimum readings were actually 0.9°F (0.5°C) **below** normal (Table 1). The average daily range was 2.6°F (1.4°C) above average in May 1987, because maximum temperatures averaged 7.0°F (3.9°C) warmer than normal. Minimum temperatures were also much warmer than expected; the overall monthly mean was 5.6°F (3.1°C) above normal. By contrast, the average daily range in May 1986 was 3.0°F (1.7°C) below normal due to cool days and warm nights under a cloudy, humid, rainy weather pattern (Table 1).

Conditions for May 1986 indicate that the two most critical factors controlling the diurnal temperature range are cloud cover and the amount of moisture in the air. May 1986 received more than 7 inches (18 cm) of rain, 3.71 inches (9.42 cm) above normal, and only 56% of possible sunshine as cloudy skies prevailed on 21 days (Table 1). By comparison, May 1988 was characterized by limited amounts of both cloud cover and atmospheric moisture. The reduced cloudiness is indicated by above average insolation (73%) and a greater number of clear and partly cloudy days (23 out of 31). Lack of moisture is clearly shown by monthly rainfall which totaled 1.06 inches (2.69 cm), the sixth driest on record and 2.60 inches (6.60 cm) below normal. In many respects, weather parameters in May 1988 were similar to those from the preceding year, yet the average daily range of temperature was 3.0°F (1.7°C) higher as compared to 1987. The dew point, which indicates atmospheric mositure content, averaged only 46.0°F (7.8°C) in May 1988, almost 8.0°F (4.4°C) below the comparable value in 1987 (Table 1). Drier air masses dominated in May 1988, and this not only decreased rainfall totals below normal, but also greatly increased daily temperature ranges.

Comparative weather conditions for June. The contrast between 1988 and the two prior years is even more distinct in the June data (Table 2). Near normal conditions prevailed in June 1986 and 1987; June 1988 weather was clearly abnormal. The average daily range of 28.4°F (15.8°C) was 7.0°F (3.9°C) above normal. Daily maximum temperatures were 5.3°F (2.9°C) **above** normal, while

TABLE 4. Indianapolis weather conditions for July (first ten days of month only).

	July 1988	July 1987	July 1986	Normal
Average Daily Maximum	94.8°F	83.0°F	85.0°F	85.0°F
Average Daily Minimum	65.2	66.8	66.3	64.7
Average Daily Mean	80.0	74.9	75.7	74.9
departure from normal	+5.1	+0.0	+0.8	—
Average Daily Range	29.6	16.2	18.7	20.3
departure from normal	+9.3	−4.1	−1.6	—
Average Dew Point	54.0	68.7	66.1	—
Monthly Precipitation	0.04″	6.14″*	1.42″	1.42″
departure from normal	−1.38″	−4.72″	+0.00″	—
Percent Possible Sunshine	80%	41%	63%	67%
clear days	4	0	5	3
partly cloudy days	4	4	1	4
cloudy days	2	6	4	3

*5.09″ on 1st.

daily minimums dropped 1.7°F (0.9°C) **below** normal. June was a very sunny month: only four days were classified as cloudy, while skies were clear on 14 days; the 81% of possible insolation was 15% above normal. The monthly rainfall totaled only 0.36 inches (0.91 cm), which made June 1988 the driest on record (dating back to 1871). The lack of rainfall was due to a lack of appreciable moisture in the air. The extremely low average dew point of 50.7°F (10.4°C) stands in stark contrast to average dew points greater than 60.0°F (15.6°C) in June 1986 and 1987, years of normal rainfall (Table 2).

July 1988 weather. The weather of July 1988 was distinguished by extremely high daytime temperatures (Table 3). On 16 days, daily highs reached 90.0°F (32.2°C) or higher, exceeding 100.0°F (37.8°C) three times. The record-tying 103.0°F (39.4°C) temperature, which occurred on July 15, was the hottest temperature in Indianapolis since 1936.

The weather of July 1988 was divided into two distinct but opposite patterns. The drought pattern and abnormal conditions of May and June continued through the first 10 days of the month. A complete transition then returned weather patterns to more normal conditions over the last three weeks of July. Between July 1 and 10, both daily maximum temperatures and daily ranges of temperature were more than 9.0°F (5.0°C) above normal (Table 3), and clear skies, dry air, and negligible rainfall continued to prevail. Insolation was high (80% possible sunshine), and average dew points were low (54.0°F or 12.2°C). The only rainfall in the 10 days fell on July 10 at the onset of a wetter regime and the end of the drought pattern.

Daily temperatures remained 2.0-3.0°F (1.1-1.7°C) above normal for the rest of the month, but the average daily range dropped to 22.0°F (12.2°C) (Table 3). Cloudy skies occurred on 10 days (of 21) and reduced insolation to 59% of possible and slightly below the norm. Over the three-week period, 4.67 inches (11.86 cm) in rainfall were received, 1.77 inches (4.50 cm) above average. Dew points rose to near 70.0°F (21.1°C), reflecting higher moisture in the air, which not only contributed to greatly increased precipitation but to lower daily temperature ranges as well. Conditions from July 11-31 were much closer to normal.

Comparative weather conditions, first 10 days of July. Only the first 10 days of July were analyzed in comparing weather conditions in 1988 to the two preceding years and to normal values over the 10-day period. Daily maximum temperatures averaged 94.8°F (34.9°C) between July 1 and 10, 1988, 9.8°F (5.4°C) above normal, causing daily ranges to average 9.3°F (5.2°C) above normal (Table 4). In both 1986 and 1987, diurnal ranges were below normal over the same period, as minimum temperatures remained warmer than average overnight. The main factors which resulted in the extreme daily temperature ranges during the first part of July 1988 were limited atmospheric moisture content and lack of cloud cover. The average dew point for the first 10 days of the month was only 54.0°F (12.2°C), and rainfall was negligible. The predominant clear skies and dry air allowed maximum daytime heating, pushing daily highs above 90.0°F (32.2°C) on eight days and producing the anomalously high temperature ranges.

In contrast, the same period in July 1987 was very wet, as rainfall was well above normal with 6.14 inches (15.60 cm) for the month and a record 5.09 inches (12.93 cm) on July 1. The high dew point (68.7°F or 20.4°C) reflects the large amount of moisture in the air (Table 4). Cloud cover shows a similar distinction between the two years: the 10-day period in July 1988 received 80% possible insolation with only two cloudy days as compared to only 41% possible insolation and six cloudy days through the same period in the preceding year. The cloudy, humid, wet regime in 1987 limited the diurnal temperature range to only 16.2°F (9.0°C), a departure of 4.1°F (2.3°C) below normal over the first 10 days of the month. Weather conditions between July 1 and 10, 1986 were normal in most respects (Table 4), in sharp contrast to those in either 1987 or 1988.

CONCLUSION

The early summer of 1988 in Indianapolis, Indiana was characterized by an extended period of hot, dry weather. Once established, the pattern persisted into early July. Widespread drought ensued, as skies remained cloud-free and little rainfall occurred. The recurring clear skies and dry air responsible for the drought also favored large daily temperature ranges. Days were sunny and hot, with daytime heating at a maximum and high temperatures climbing well above normal. On the other hand, nights were cool and clear, and minimum temperatures dropped below normal as cloudless skies facilitated rapid radiational cooling. From May through July 10, diurnal ranges in temperature averaged more than 28.0°F (15.6°C), an increase of 31% above normal.

Throughout the period, a stationary ridge of high pressure suppressed the development of clouds and rainfall. Cloud cover and moisture content are the two most important factors controlling the diurnal range of temperature, so the absence of clouds and limited supply of moisture greatly increased daily temperature ranges. The percent of possible sunshine was 14% above average during the early summer, with less than half the normal number of cloudy days. The dryness of the air was clearly indicated by low dew point temperatures around 50.0°F (10.0°C), in sharp contrast to average dew points in the preceding two years. Rainfall between April 23 and July 9 measured only 1.53 inches (3.89 cm), 15.9% of the rain expected in Indianapolis during that period. Total rainfall was 29% of normal in May, only 9% of normal in June, and just 3% of normal over the first 10 days of July. June was the driest on record dating back to 1871.

The persistent combination of clear skies, dry air, and minimal rainfall that prevailed during the early summer 1988 produced unusually large daily ranges in temperature in Indianapolis, Indiana. In comparison to earlier years and to climatic normals, the weather conditions experienced in May, June, and early July 1988 represent a climatic anomaly which departed significantly from normal.

Given the recent occurrence of a severe drought in early summer 1988, the present paper is a descriptive analysis of both the anomalous conditions associated with the hot, dry weather and accompanying unusually large daily ranges in temperature. This analysis raises several questions for further research: how abnormal were the high daily temperature ranges experienced in Indianapolis, Indiana during the past summer; what significant correlations exist between daily range and moisture (rainfall, dew point temperature) or cloud cover (number of cloudy days, percent of possible sunshine); what is the estimated return period for the occurrence of extreme events such as severe drought or abnormal daily temperature ranges?

Another set of questions broadens the geographic scope of the research. As noted previously, the drought was characterized by widespread areal coverage. How extensive an area was affected by extreme high daily temperature ranges? How do abnormal temperature values in Indianapolis compare with normal conditions at steppe and desert climatic locations to the west across the Plains? What regional patterns were displayed by the temperature anomalies produced by the persistent hot, dry weather of early summer 1988? Work is already in progress to compile data from a number of stations throughout the drought-afflicted region and to review applicable literature for comparative purposes in examining the abnormal temperature and rainfall conditions in historical perspective.

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HISTORY OF SCIENCE

Chair: HARRY G. DAY
Department of Chemistry
Indiana University
Bloomington, Indiana 47405

Chair-Elect: B.F. SWARTZ, JR.
Department of Anthropology
Ball State University
Muncie, Indiana 47306

ABSTRACTS

On the Value and Use of Antique Scientific Apparatus. JOSEPH J. BELLINA, JR., Saint Mary's College, Department of Chemistry and Physics, Notre Dame, IN 46556.—Many schools whose histories extend into the 19th century have collections of apparatus which may be a valuable resource for education in science. This very old, but frequently ignored equipment can be refurbished and used to interest students in science. The simplicity and quality of construction of these devices make them especially useful for lecture demonstrations or hallway displays. I will describe my experiences with equipment which was originally purchased by Saint Mary's College and by the University of Notre Dame between 1860 and 1895. The discussion will include information on collecting, identifying, refurbishing, displaying, storing, using, and if necessary, disposing of these valuable and attractive pieces of equipment.

Back to the Archives for a Lecture. DONALD J. COOK, Chemistry Department, DePauw University, Greencastle, IN 46135.—Modern day chemistry classes cannot be taught at a pace which allows the instructor to present much of the historical observations and facts which were the basis for the science. Today much must be abbreviated or omitted in any chemistry class in order to satisfy the pertinent knowledge of the subject. In order to still give the student a historical feel for the long range development of the science and the many small steps necessary before long strides could be taken in chemistry, the author proposes that during each academic year the undergraduate student be exposed to one or two lectures which illustrate some unique story in the development of chemistry. To find these materials the lecturer is referred to the departmental archives and historical publications. Illustrations will be taken from the following list: 1) the legacy of Priestley and Lavoisier; 2) Dalton, Gay-Lussac, Avogadroe, and Cannizzaro; 3) Mendeleev's Periodic Chart; 4) Wöhler and Liebig; 5) the LeBlanc Process and the Solvay Process; 6) Kekule and the Benzene Ring; and 7) Pasteur and Molecular Asymmetry.

How Museum Exhibitions, Artifacts, and Innovative Programming Can Make Science History Come Alive! VIRGINIA V. HAMM, Indiana State Museum, 202 N. Alabama, Indianapolis, IN 46204.—In February of 1987, the Indiana State Museum hosted the exhibition MAGNIFICENT VOYAGERS: The U.S. Exploring Expedition, 1838-1842, a wonderful chronicle of the first scientific exploration voyage sponsored by the U.S. government in 1838. The purpose of the voyage was to gather scientific specimens from around the world and to map and chart the islands, lands, and seas. America intended to join the European scientific community! The specimens collected became the base collection of the Smithsonian Museum of Natural History. This exhibition allowed visitors to step back in time and see the world through the eyes and diaries of the participants. The Educational programs about Seashells, Seachanties, Volcanos, Storytelling, Map-reading, and Urban Voyaging (orienteering) drew in serious and avocational scientists, families, school children, teachers, scouts, and historians. These and other exhibition enhancing programs are making science history come alive!

The Challenge of the Mind...Engineering Education, Then and Now. NILS I. JOHANSEN, P.E., Engineering Technology, University of Southern Indiana, 8600 University Boulevard, Evansville, IN 47712.—Engineering and science education needs to be relevant. One of the best ways to assure this is, in the author's opinion, to draw upon lessons from history. Today's engineers and scientists need to be aware of the past so they can chart a course for the future. The presentation traces the development of engineering education through the writing of Georgius Agricola (1556), examples of engineering work of the Renaissance, and some of the large engineering projects of yesterday and today. The presentation is a sample of some of the issues and stories covered in the author's courses in engineering and specifically a course in history of engineering.

A History of Physics Course as a Capstone Course in Liberal Arts Curriculum at I.S.U. L. GENE POORMAN, Department of Physics, Indiana State University, Terre Haute, IN 47809.—The history of physics course at I.S.U. is designed as a capstone course for the liberal studies curriculum. The course material includes selected topics from Stonehenge to quarks. Students write three papers: 1) contributions of Physics Nobel Laureates to society, 2) correlation of society and a big idea in physics, and 3) the role of physics in man's environment. The culmination event is a learned paper delivered in a learned way to the class.

The Search for a Knowledge Base in Education: The Failure to Incorporate Communications Science Into Science Teaching. JOHN RICHARD SCHROCK, Division of Biology, Emporia State University, Emporia, KS 66801.—In 1972, Benjamin Bloom underscored the lack of any recognized body of knowledge in education comparable to the paradigms that drive the successful science enterprise. The last twenty years have seen educational "innovations" rise and fall in five-year cycles, including the audio-tutorial lab and computerized bio-education movements based with Indiana scientists. Communications science and sensory biology have the potential to explain the effectiveness of most "innovations" but current efforts to proclaim a knowledge base for pedagogy are exclusing communcations science and reality-based science inquiry.

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HAUROWITZ AND PAULING

E. CAMPAIGNE
Chemistry Department
Indiana University
Bloomington, Indiana 47405

In the fall of 1948, I had the honor and pleasure of introducing to one another two giants in the field of immunochemistry, Felix Haurowitz and Linus Pauling. There was some drama in this meeting, which occurred at Indiana University, and the story merits the telling.

These two certainly were familiar with each other's work through the scientific literature, but by the nature of world affairs during the previous 10 or 15 years, it is unlikely that Linus Pauling ever anticipated meeting Felix Haurowitz, upon whom he had relied so heavily in developing his theories of antibody formation, and certainly not in a small town in Indiana.

Felix Haurowitz was born in Prague, the capital of Bohemia, in 1896. After serving in the Austrian Army, he enrolled at the German University of Prague, where he received the Doctorate in Medicine in 1922 and the Doctorate in Science in 1923. His natural interest was in chemistry and mathematics, so while in school, he volunteered to work in the Department of Physiological Chemistry, headed by Prof. Dr. Richard von Zeynek, a hemoglobin chemist. Later, von Zeynek appointed Felix to a half-time assistantship and then to a full-time appointment, after Felix received the M.D. degree (1922). During his student days, Felix also spent a semester at the University of Wurzburg in Bavaria, where he spent some time in the organic preparative laboratory of Prof. Stephen Goldschmidt. He also found time to visit the famous, but retired, biochemist Franz Hofmeister.

Following completion of the D.Sc. in 1923, Haurowitz spent the summer months in the laboratories of Rona and Michaelis in Berlin. This laboratory was internationally renowned for physical chemistry, and Haurowitz was anxious to learn the use of hydrogen electrodes and pH measurement, a new technique being developed in the Michaelis laboratory. He spent some time working on blood serum there. In 1924, Felix worked in Willstätter's laboratory in Munich. Willstätter was an organic chemist, who had received the Nobel prize in 1915 for his work on chlorophyll and prophyrins. Willstätter at this time was working on enzymes, and a paper on the nature of gastric lipase resulted from their collaboration. While Felix was in Munich, he felt the first severe impact of Hitler's insidious anti-Semitic propaganda, when Willstätter resigned from the University, because a qualified Jewish nominee for an important academic post was rejected by the Faculty. Even then, in 1924, some students wore the "hooked cross" but were embarrassed to wear it in Willstätter's presence. The whole tragic incident is described in Willstätter's autobiography (1949).

In 1924, Haurowitz, at the suggestion of the colloid chemist Liesegang, completed the first of his internationally acclaimed series of volumes on "Progress in Biochemistry." Later volumes appeared in 1931 and 1938, and Pauling must have been familiar with these.

In 1925, Haurowitz submitted his several papers on hemoglobin as a thesis for the docentship at the German University of Prague, and he began to give courses on Biophysical Chemistry and Advances in Biochemistry. Following his appointment, he received an invitation to work in the new Protein Research Institute in Heidelberg from its director, Professor Albrecht Kossel. Kossel was well-known for his fundamental work on protamines and histones, for which he had received the Nobel prize in 1910. He was also Editor of *Hoppe-Seyler Zeitschrift für Physiologische Chemie,* the oldest biochemical journal in the world. Following a semester at Heidelberg, Haurowitz returned to Prague and continued work on hemoglobin and derivatives.

In 1930, he was given tenure as Associate Professor of Physiological Chemistry in the Medical School of the German University of Prague. It was now that he began his work on immunochemical problems, the research area that became his principal life-time effort and for which he became internationally famous. A young colleague, Fritz Breinl, had just returned from a year at the Rockefeller Institute and spoke of Landsteiner's experiments with synthetic haptens. Haurowitz became immediately fascinated by the mystery of how antibodies might be formed. After some collaborative experimental work, these two advanced a theory (Breinl and Haurowitz, 1930) that antibodies are globulins whose molecules are adapted complementarily to the determinant groups of antigen molecules. This became known as the "template" theory, and it served as a great stimulus to research in the field. It was the first viable theory that differed from the early suggestions by Paul Ehrlich (1900) that antibodies against all possible antigens were already present in blood.

Haurowitz continued his work in the field and became an authority in immunochemistry. In the spring of 1939, the Nazis occupied Sudetenland, and the German University of Prague became an independent university of the German Reich. Haurowitz was mobilized by the Czech army and asked to organize a military hospital. Soon after, he was notified that he had been "temporarily deprived" of his privilege to teach and to examine students. An offer of a chair of Biochemistry at the University of Istanbul permitted him to leave Czechoslovakia with his family for Istanbul just as Hitler invaded Prague. He remained in Turkey until 1948. It is typical of Haurowitz that during this period of reduced research effort, he published a biochemistry text in Turkish.

Linus Pauling was born in Portland, Oregon, in 1901. He received a bachelors degree in Chemical Engineering from Oregon Agricultural College (now Oregon State University) at Corvallis in 1922 and proceeded immediately to the California Institute of Technology as a graduate assistant in chemistry. He received the Ph.D. in Physical Chemistry in 1925. He held a National Research Council Postdoctoral fellowship, 1925-26, at Cal. Tech, associating with Robert Millikan, then director of the Norman Bridge Laboratory of Physics and President of the University, and Arthur A. Noyes, Director of the Gates and Crellin Laboratory and Professor of Physical Chemistry. Among his good friends that year was another N.R.C. Postdoctoral Fellow, Frank T. Gucker, just out of T.W. Richards' laboratory at Harvard. Gucker was Chairman of the Chemistry Department at Indiana University at the time of Pauling's visit.

In 1926, Linus Pauling was awarded a Guggenheim Postdoctoral fellowship for study abroad and spent his time working in the laboratories of such noted scientists as Arnold Sommerfeld in Munich, Niels Bohr in Copenhagen, and Erwin Schrödinger in Zurich. He returned to the California Institute of Technology as an Assistant Professor in 1927, where he rose rapidly through the ranks to Professor in 1931 and Chairman of the Division of Chemistry and Chemical Engineering and Director of the Gates and Crellin Laboratory in 1936.

Pauling's early work focused on crystal structure and the chemical bond. He published a series of seminal papers on "The Nature of the Chemical Bond" lbetween 1931 and 1933 in the *Journal of the American Chemical Society* and the *Journal of Chemical Physics*. In the fall of 1937, he held the George Fisher Baker Nonn-resident Professorship of Chemistry at Cornell University, which enabled him to complete his book (1939), *The Nature of the Chemical Bond and the Structure of Molecules and Crystals*. This volume, which has gone through three editions, has been called one of the most influential scientific books of the twentieth century.

In 1934, Pauling began to apply his knowledge of molecular structure and the nature of chemical bonding to more complex molecules, particularly to the structure of proteins. His studies of the magnetic susceptibility of hemoglobin molecules during oxygenation must have overlapped with the work of Haurowitz, who had worked extensively with hemoglobin and oxyhemoglobin from 1922 to 1936. Indeed, Haurowitz, writing of his own work on crystalline hemoglobin and oxyhemoglobin, noted that after his first discovery of a second hemoglobin (hemoglobin F), hemoglobins S, C, M, and others were discovered a few years later by Pauling, Itano, *et al.* (Haurowitz, 1975).

Following this work, Pauling began a series of studies of protein, which led to a theory of the structure of native, denatured, and coagulated proteins. This led naturally to proteins involved in immunological reactions, and in 1940, Pauling published his now classic paper entitled "A Theory of the Structure and Process of Formation of Antibodies."

In the late summer of 1947, Indiana University was in the process of installing a new chairman of the Chemistry Department, Prof. Frank T. Gucker of Northwestern University. Gucker was considering Felix Haurowitz as his first appointment in biochemistry, on the recommendation of Prof. H.G. Day. Day had become aware of the availability of Haurowitz, who was at that time still on the Faculty of Medicine at Istanbul, through Alice Haurowitz, his daughter, who was then a student at Indiana University and had been living with the Days. Since I had received my degree in biochemistry from Northwestern (1940) and was at that time teaching some of the biochemistry laboratory work at Indiana, Gucker asked me to review the Haurowitz file of reprints.

As I translated the German of the Breinl and Haurowitz paper of 1930, I had the feeling that I had read this before. Turning to my files of the *Journal of the American Chemical Society*, I pulled out Pauling's 1940 paper and was amazed at the similarity of the proposals! In his opening paragraph, Pauling stated that the idea of complementary structures for antibody and antigen was suggested by Breinl and Haurowitz in 1930. After outlining his proposal that antibodies differ from normal serum globulin only in the way in which the two end parts of the globulin polypeptide chain are coiled, and that these end parts. can assume a very great many configurations with nearly the same stability to conform to the configuration of the surface regions of the antigen Pauling noted (1940, p. 2654), "The only data permitting a quantitative test of this relationship (predicting the valence of two or more different haptens in the same antigen) which have come to my attention are those obtained by Haurowitz and his collaborators by use of azoproteins made from arsanilic acid."

It was apparent that the Pauling paper was proposing almost identical ideas for the formation of antibodies! The major difference in the two theories was later described by Haurowitz (1960) in an historical review as follows: "I assumed that the antigen molecule is deposited in the sites of globulin formation and interferes with this process by directing the amino-acids, during the process of biosynthesis, into such positions that the synthesized globulin is spatially adapted to the determinant group of the antigen. Pauling later (1940) modified this view and assumed that the peptide chain, after formation, folds around the determinant group of the antigen in such a manner that a complementarily adjusted group in the antibody molecule is formed. I am inclined to share this view and to assume that the difference between normal serum globulin and antibody is indeed only a difference in the mode of folding of the peptide chains."

By 1968, Haurowitz had reverted to his original ideas, and wrote as follows: "Pauling's views seemed very plausible at the time, when nothing was yet known about the close correlation between primary structures and conformation of proteins. Pauling's idea was supported by reports of almost identical amino-acid composition of various antibodies, and by reports that the N-terminal pentapeptide is identical in rabbit antibodies and normal γ-globulin. Improved methods of amino-acid analysis have now actually shown small but significant differences between antibodies of different specificity."

In the fall of 1947, Felix Haurowitz accepted a position as Professor of Chemistry at Indiana University and planned to arrive in the United States from Istanbul in the summer of 1948. In the meantime, Professor Gucker had taken charge of the department on his arrival in September of 1947 and inaugurated a number of new initiatives. One of these was the establishment of a new local section of the American Chemical Society. Previously, the chemistry faculty, as members of the A.C.S., had to travel to Indianapolis, fifty miles away, over winding old State Road 37 (no four lane through-ways in those days) to attend the monthly meetings. Needless to say, attendance was poor. Frank Gucker was a strong supporter of Chemical Society activities and proposed that we have our own section. He appointed a two-man committee (with me as chairman and a graduate student for support) to collect the needed signatures and to carry out the formalities required by the national organization to establish a local section. The Inaugural meeting of the Southern Indiana Section of the American Chemical Society was set for October, 1948. The principal speaker was to be the President of the American Chemical Society, Linus Pauling, who was to speak on "The Formation of Antibodies."

As first President of the new local section, it was my duty to host the speaker and to introduce him around the department. I looked forward with pleasure to this honor, and when Pauling arrived for his lecture, which was scheduled for eight o'clock that evening in the Chemistry Auditorium, the first office I took him to was that of Professor Felix Haurowitz. I said, "This is Felix Haurowitz. You probably know him." Pauling exclaimed, "Not **the** Felix Haurowitz!" "Yes," I said, "you work in the same field."

I left Haurowitz and Pauling in animated conversation, but I couldn't help wondering what Pauling would say that night when he talked on "The Formation of Antibodies." The two men differed very much in their styles. Haurowitz was very quiet and reserved. He never made a statement in his scientific work which did not have solid experimental backing, and in his proposed theories, he always indicated areas which needed experimental backing. He himself stated, discussing his template theory, "As a chemist, I have tried to translate this picture into the language of chemistry." He didn't draw many imaginary pictures of antigens and antibodies, as Ehrlich had done earlier. Pauling, on the other hand, was much more willing to go out on a limb. He loved to apply what he called the "Stochastic" method, the application of intuitive hunches based on chemical facts, for which he had a phenomenal memory. He used many diagrams and visual images of proteins, antigens, and antibodies in his first paper (1940) and in his lecture. "His success as a scientist is based on his capacity for quick insight into new problems, his ability to recognize interrelationships, and the courage to put forward unorthodox ideas. While his concepts have not always been correct, they have always stimulated discussion and investigation" (Encyclopedia Britannica, 1979).

The difference in these men is illustrated in a story Haurowitz later told. In follow-up experiments based on his theory, Pauling claimed that he could synthesize antibodies *in vitro* by exposing slowly renaturing globulin to antigens (Pauling and Campbell, 1942). Haurowitz repeated these experiments and showed that antibodies were not formed in this way; the observed precipitate did not involve complementary reaction. Haurowitz wrote this up, submitted the manuscript to Pauling with the suggestion that Pauling submit a correction, and offered not to publish in that case. Pauling, of course, said "no." Felix should publish his results, and let the scientific world be the judge. Haurowitz (Haurowitz, *et al.,* 1946) did publish and later, a postdoctoral student of Pauling's, working at Cal. Tech in 1948-49, was unable to confirm that claim (Morrison, 1953).

The lecture hall was filled that night, and there were many laymen present to hear the great man speak. Pauling was equal to the occasion. He is a flamboyant speaker and a popular lecturer. In order to be better seen and heard in the large auditorium, he climbed up on the lecture demonstration desk, which was large enough so he could walk back and forth. He began, "I visualized that if God was going to form antibodies, He would form them in the simplest way, and these antibodies are therefore merely coiled up chains of amino-acids, and nobody ever thought of that before except HAUROWITZ," and he turned and pointed at the Professor, sitting in the front row! He continued to present the various aspects of his theory, each time ending with a spectacular, "and nobody ever thought of that before, except Haurowitz," pointing to the man in the front row. The evening was a great success. A layman in the audience reported, "I didn't understand a word he said, but it was one of the best lectures I ever heard."

Since that autumn day in 1948, both men have gone on to greater honors. Haurowitz won the Ehrlich medal in Germany, was elected to the Leopoldina Academy, the U.S. National Academy of Science, the American Academy of Arts and Sciences, and an honorary M.D. from the University of Istanbul and an honorary Sc.D. from Indiana University. Pauling continued to occupy the public eye and received numerous honorary degrees, both here and abroad. He received the Nobel Prize in Chemistry in 1954, the Nobel Peace Prize in 1962, and the International Lenin Peace Prize in 1972. For a while, he served as Research

Professor at the Center for Study of Democratic Institutions and is now Research Professor in the Linus Pauling Institute of Science and Medicine, where his proposals on megavitamin therapy, especially vitamin C, are still stimulating discussion and investigation.

ACKNOWLEDGMENTS

In addition to the specific references given, I am indebted for general insight into the character of these two gentlemen to the following works:

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2. "The Chemistry and Biology of Proteins," F. Haurowitz, Academic Press, Inc., New York, 1950.
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I am also indebted to Marvin Carmack for assistance in translating the pages of Willstätter's (1949) autobiography.

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DR. RYLAND T. BROWN, 1807 - 1890: MEDICAL TOPOGRAPHY, SCIENTIFIC AGRICULTURE, AND GEOLOGICAL SURVEYS

Wilton N. Melhorn and Steven G. Kenaga
Department of Earth & Atmospheric Sciences
Purdue University
West Lafayette, Indiana 47907

ANALECTA

Ryland Thomas Brown, M.D., A.M., has been relatively ignored by recent geological survey historians, but he was one of a small, select band of naturalist geologists that served the State of Indiana in the middle years of the 19th century. Although his career temporally paralleled that of the famous brothers Owen, David Dale and Richard—Brown was born in 1807, as was David Dale, and died in 1890, the same year Richard was an accidental suicide through imbibition of embalming fluid—and although all had attended the Ohio Medical College in Cincinnati, there seem to have been few if any professional contacts or interrelationships. This is curious, considering the limited number of scientifically trained individuals in those days, but several hypotheses can be advanced in an attempt at explanation.

The first supposition is that whereas Brown came from an improverished, rural setting in southeastern Indiana, and later moved to the frontier community of Crawfordsville in the "upper Wabash Country", the Owens carried the imprimatur of inherited wealth, gentility, and breeding, and had long been exposed to the illustrious, albeit peripatetic, scientific milieu of the New Harmony colony. Thus, perhaps there existed an unwritten, but real, social and economic stratification in the generally egalitarian semi-frontier setting that was Indiana in the first half of the last century.

Second, although all these men had trained for the medical profession, only Brown seems ever to have actually engaged in medical practice, meanwhile retaining, at least in later years, a strong interest in what today is called "medical geology"; Brown (1882, p. 94), in fact, coined the term "medical topography." David Dale, however, clearly acquired a medical background only to assist in pursuit of his chosen profession of stratigrapher and paleontologist. Richard, the most unpredictable of all, progressively moved from geology to humanitarian pursuits and, in later years, to a dedication to the idealistic dream of scientific education for the common man, an idea outlined originally by his father, Robert Owen, before and during the halcyon days of the New Harmony "experiment."

Third, Ryland Brown, abetted by then-Governor Joseph Wright, actively led a campaign for establishment of a state geological survey during the 1850's, a time when the Owens were largely absent from Indiana, busily engaged elsewhere on geological surveys that ranged from Arkansas to the Minnesota Territory.

Finally, after the hiatus caused by the Civil War, David Dale was suddenly deceased, at a relatively early age; Richard had moved to academia in indirect pursuit of the land-grant college concept, then stirring at the national level because of the 1862 passage of the Morrill Act; and Brown, perhaps for the first time in his life, held a reasonably secure position as Professor of Natural Sciences at Northwestern Christian College in Indianapolis.

Our research does not reveal which, if any, of the foregoing suppositions is most plausible; perhaps in some way all played a role. But it is of special interest that Richard Owen, writing the preface for transmission of the 1862 volume of the second Owen survey, of 1858-59, to the State Board of Agricullture—the same agency for which, as we will see, Brown had prepared a geological report in 1854!—fails any mention of Brown's contributions. Perhaps, in brief, the Owens merely chose to ignore Ryland Brown, either because of professional jealously, or the simple belief that Brown was not a geologist at all. If the latter, only Brown's county geological survey reports of later years remain with us to show how mistaken was Richard Owen.

THE EARLY DAYS

Ryland Brown was born in Mason (now Lewis) County, Kentucky on October 5, 1807, of Welsh and English parents. His intellectual strengths seem mostly to have been inherited from his mother, Hannah John Brown, and his maternal grandfather, who bore the improbable name of John John. In 1808, the family moved to Clermont County, Ohio, where R. T. started at age four a common school education under a Yankee school master. In the spring of 1821, the Browns moved to the wilderness of southeastern Indiana, starting a farm in Rush County. Though by now any formal, early schooling was over, apparently Ryland was a voracious reader, and even in Rush County, there were sufficient books to engage his interest. Family recollections (C. Brown, 1927) show that Ryland tended towards "a weakness of the lungs", so that for a time he gave up farm work to become a field guide for land-hunters and speculators flooding into the new territory. It was in this role that Brown likely honed his interests as a naturalist, especially in learning all he could about trees and the medicinal properties of "weeds", as many herbs and plants were called. Perhaps the limestone ledges and outcrops of Rush County were also intriguing; and if the "weakness" was an early stage of tuberculosis, as seems likely, no better cure in those days than constant life as an outdoorsman!

Ryland's father, George Brown, a veteran of the American Revolution, died in 1825, leaving a destitute family on a scrub-woods farm. Meanwhile, Hannah had acquired, despite any formal training, a considerable reputation as a physician (Dunn, 1919, pp. 1789-1790):

> There were few physicians and in their absence she sent to Cincinnati for the necessary books, studied medicine and became widely known for her capable service as a physician. She did not practice the work as a profession, and administered unselfishly to all...So far as the records are obtainable she was the first woman physician in Indiana. It was from her that her son Dr. Ryland T. Brown gained his first knowledge of medicine.

Women physicians were unheard of in the 1820's, nor could a woman have entered any medical college. Likely we would think of her today as a midwife and nurse's aide—presiding over deliveries, prescribing herbal tonics and drugs, perhaps even attending simple breaks and cuts, all common on the frontier. Her ambitions were to be realized in her son, and payment for her services likely was "in kind", or a few coppers slipped under the table.

In 1826, R. T. began teaching in the common schools and studied medicine in his spare time, probably from the books his mother had acquired. From 1827 to 1829, Ryland attended sessions of the Ohio Medical College, receiving his M.D. in the latter year. Family recollections do not show how he paid for this, considering a lack of "tangible resources" (C. Brown, 1927). Having married in the autumn of 1829, he practiced medicine from a log cabin near Rushville until 1832, when the family moved to Connersville, where Brown established a medical practice.

Evidently not all was financially rosy for the young physician, but he had auxiliary means of support. Brown had joined the Baptist Church in Rush County at age 15 and gave his first sermon at 19. He then fell under the spell of the writings of Alexander Campbell, and an increasingly vocal espousal of Campbellite revisionist doctrine eventually led to his arraignment and expulsion from the Baptist Church. Undeterred, Brown quickly became a leader in the separatist movement as it gathered strength and eventually became the Christian Church. Helping found the local Christian Church whilst in Connersville, he devoted an increasing amount of time to the pulpit, thereby probably improving his finances, but little helping the medical practice. Ten years of double effort, in fact, led by 1842 to a recurrence of his respiratory woes, which as a doctor he wisely arrested by giving up both medical and pastoral activities to work for a year as a tree-cutter and in an open-air sawmill.

CRAWFORDSVILLE AND CRINOIDS

Sometime in the spring of 1844, Brown became enamored of the idea that opportunities existed along the new frontier then opening up in the Wabash Valley and set out by wagon with his family to settle in "Wabash Town", where he remained only six weeks before his wife became seriously ill of malaria. After an arduous trip to and a brief stay in Lafayette, he travelled over abysmal roads to Crawfordsville, where fellow Masons helped find a house where he could establish a medical practice.

We are uncertain as to the location of "Wabash Town". It may have been one of the riverboat communities that sprang up along the Wabash and Erie Canal. Perhaps it was somewhere in Fountain County, which explains why Brown many years later returned to this area to prepare the first of his six county geological reports.

Brown remained in Crawfordsville until August, 1858, when he removed to Indianapolis to assume the Chair of Natural Sciences at Northwestern Christian College. The 15 years in Crawfordsville must have been happy ones. Not only did his financial fortunes improve, he lived next door to a college, and there were books to be had! Wabash College already had a considerable reputation, an excellent library for the time, and laboratories with scientific apparati. Further, Wabash had the senior Edmund O. Hovey, the same man who would so influence other great Indiana scientists, such as Stanley Coulter. Apparently Brown also fell under Hovey's charm and knowledge. Although the archives of the college hold little to tell us more, either of Brown or Hovey, it is reported that Brown "completed essentially the entire curriculum in the Natural Sciences" (Herring, personal communication), apparently so successfully that he was awarded an A.M. degree (Honorary) in 1850.

Undoubtedly, it was here that Brown acquired his formal knowledge of paleontology and geology, though the earlier experiences amid the rocks and forests of Rush County and the brief stay in the coal fields of the Wabash Valley—coal became of continuing interest to Ryland—likely made him a receptive learner. The world-famous crinoid beds along Sugar Creek, north of town, had been discovered by Hovey in 1836, and although systematic excavation at what became known as Corey's Bluff did not commence until the mid-1850's, surely Brown would have accompanied Hovey to this and other exposures, learning stratigraphic paleontology as he went.

THE INDIANA STATE BOARD OF AGRICULTURE

All nineteenth century, state-sponsored geological surveys of Indiana had ties to the Indiana State Board of Agriculture, for at that time geology and agriculture were closely connected. It already was recognized that soil characteristics are greatly influenced by the geologic materials from which soils are derived; therefore, such topics as soil fertility, erosion, and drainage were addressed by the men doing geologic work. The acts of the Legislature that authorized both Owen surveys and the Cox survey list soil analysis as a duty of the State Geologist.

The State Board of Agriculture, created by the Legislature in 1834 on the request of Governor Noah Noble, was to oversee the establishment of county agricultural societies for the purpose of disseminating agricultural information. This fledgling Board wasted no time in asking the Legislature for a geological survey. In the first report, the Board (Committee of Agriculture, 1835, p. 4) reported to the Legislature that "...[it] would be pleased to see an agricultural, in connection with a geological survey of the state, as recommended by the Executive."

The requests of the Board of Agriculture and the Governor brought about the Owen survey of 1837-38. Unfortunately, the secretary of the Board of Agriculture moved away in 1837, and the agency made no report that year. It was a fatal blow; by 1839, there was no longer a Board of Agriculture.

Although Ryland Brown (Figure 1) is the focus of this paper, other people who merit special attention commonly are discovered during background research. Joseph A. Wright, Governor of the State of Indiana from 1849 to 1856, is such a person. Wright had been a young representative from Parke County at the time the State Board of Agriculture was established in 1834. He viewed "scientific agriculture" and development of natural resources as the key to increasing the wealth of the State and improving the quality of life for her citizens. Wright was not a farmer and possessed no scientific training in agriculture, but he had a passion for the subject (Esarey, 1922, p. 822), and delighted in associating himself with men of science. Wright was convinced from the wretched state of most farms that educating farmers in "scientific agriculture" was the key to improving their standard of living. To this end, in his 1851 address to the Indiana House of Representatives (Journal of the House of Representatives, 1851, p. 29), Wright asked for:

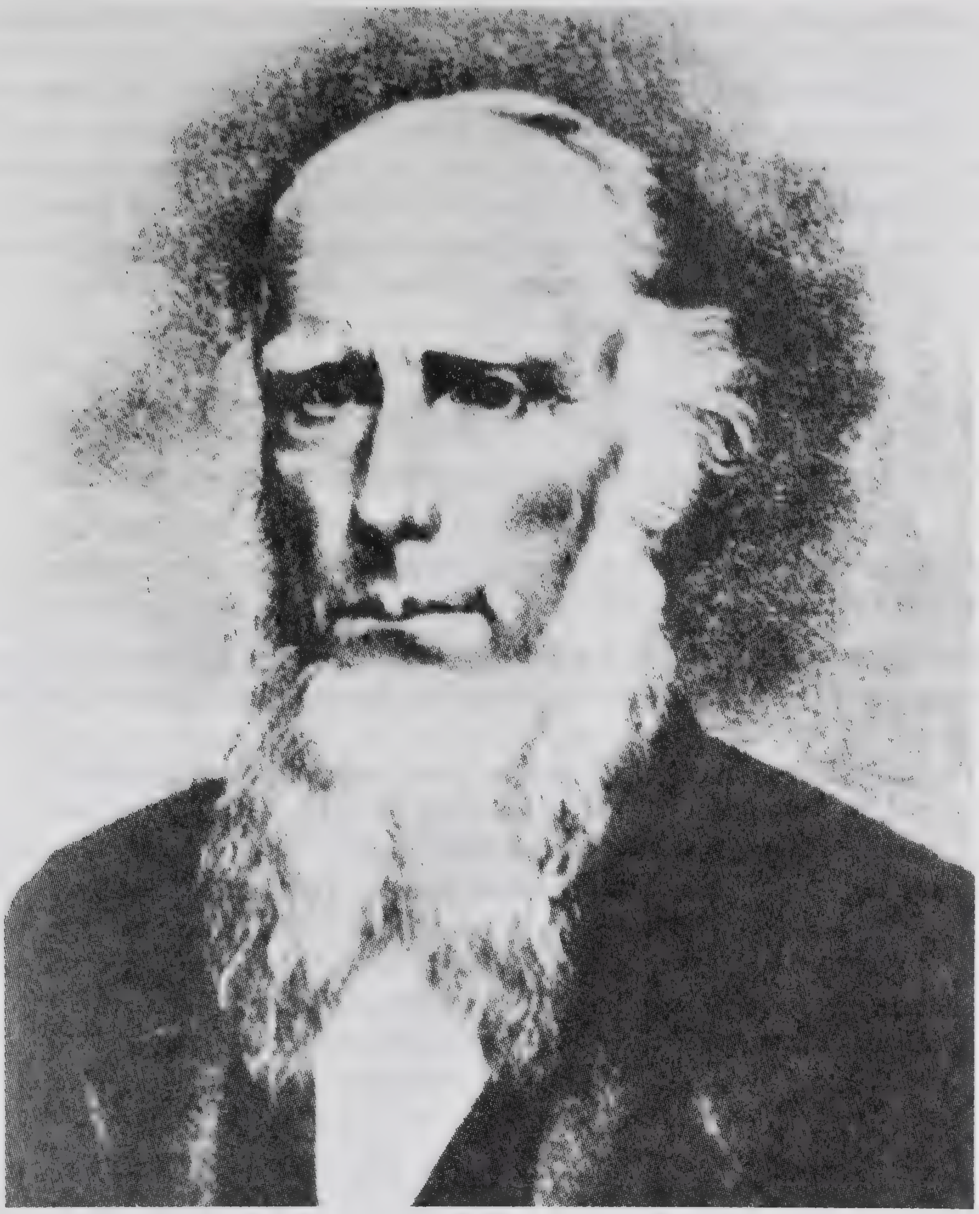

FIGURE 1. Ryland T. Brown, M.D., A.M., 1807-1890 (photo courtesy of Indiana State Library).

> The establishment of a State Board of Agriculture, to consist of, say of nine members, for the express purpose of organizing a State Agricultural Society, (and) would be calculated to bring into existence, in the several counties of the State County Societies, that would be auxiliaries to the State association.

The State Board of Agriculture, reestablished during the 1851 legislative session, was an exact duplicate of that created by the 1834 Legislature, of which Wright was a member. This time, however, Wright would make sure that the Board would not founder. The Board would be responsible for holding an annual fair at which awards would be given to farmers having the best agricultural produce, farming techniques, and inventions. It would also print an annual report to disseminate the latest in agricultural knowledge. In short, the Board of Agriculture's mission was to evangelize the concept of "scientific agriculture" to farmers that didn't think they needed it.

Critical to Governor Wright's goal of making Indiana a prosperous and self-sufficient State was the encouragement of in-State industrial development. The fact that Indiana's natural resources were being removed from the State and sold back to Indiana as manufactured goods was an irritant to Wright; the key to attracting investors was to develop and "show-off" Indiana's natural resources—geologic resources in particular. In the same address to the State House of Representatives in which he asks for the Board of Agriculture, Wright restates his position on a geological survey (Journal of the House of Representatives, 1851, p. 29):

> Your attention is again earnestly invited to the importance of providing for a thorough geological and topographical survey of the State. The interests of agriculture, manufactures, and commerce, alike demand it.

He did not get his geological survey, but the State Board of Agriculture was the perfect vehicle to carry the fight.

As first president of the Board of Agriculture, Governor Wright did not pass up the opportunity to continue to pressure the Legislature (Esarey, 1922):

> ...if we shall send out scientific men to explore our hills and prairies, to analyze our ores and soils, lay bare the now concealed riches of our mines, exhibit at one view the depth of our coal seams, the proper locations for our iron furnaces, the extent of our marble and stone quarries, the worth of our immense forests of timber, the richness of our soils, and thereby cause capital and labor to seek a place among us, and shall infuse among our farmers and mechanics a spirit of rivalry and competition, by the means of county and State fairs. ...

It is not known when or how Ryland Brown first became associated with Gov. Wright and involved with the Board of Agriculture, especially as Wright, a Democrat, was dealing in Brown with a life-long Whig! But it seems too much of a coincidence that Brown (Blatchley, 1916, p. 11) read a paper before the State Legislature in 1852 (Indiana State Board of Agriculture, 1853, p. 6) asking for money to do a survey that: "...should not only embrace the geology and mineralogy of the State, but in which the topography of each county should be carefully examined and accurately marked on the map", while Wright is simultaneously putting pressure on the Legislature for the same thing.

Dr. Brown's name first appears on the State Board of Agriculture roster in 1853, although he probably was already associated with the Montgomery County agricultural society, as it was normally the president of each county society who attended State Board of Agriculture meetings. At the first appearance of Brown at the annual meeting of the Board, Governor Wright made a sudden announcement. With no previous discussion (Indiana State Board of Agriculture, 1854, p. 36):

> Gov. Wright gave notice that he would, on to-morrow, introduce a resolution in relation to the employment of a competent person to make a Geological Survey of the State.

Gov. Wright offered the following resolution, which was adopted:

> Resolved, That the Executive Committee be, and are hereby, requested to employ, if thought practicable, a competent person (at an expense not exceeding five hundred dollars) whose duty it shall be to report at the next session of the Board, a history of the geology of Indiana, with as full a statement as his time will admit, of our ores, coal, timber, water power, &c., together with such statements and information as he may think advisable.

Gov. Wright already had a "competent geologist" in mind when he offered the above resolution:

> On motion of Gov. Wright, Dr. R.T. Brown was employed to prosecute a partial Geological examination of the State, at a salary of $500 per year.

One man, appointed by the Governor of the State of Indiana, armed with $500 and 10 months, had the task of doing a geological survey of a frontier state! It would never work, but then it was never intended to work. This is why it is unfair and misleading to compare Dr. Brown's report with the 1838 Owen report, or any other later geological report. The funding came directly from the Board of Agriculture which, as Gov. Wright must have been aware, could not afford to support a continuous, detailed geological survey. Even Dr. Brown (1854, p. 299) knew this:

> With the limited means at the disposal of the Board, I suppose it was not their intention to undertake, at present, anything like a systematic survey, and mapping of the State by sections; but merely to institute such local examinations as will, with the least labor, develop the largest amount of facts in relation to the resources of the State, not only in mineral wealth, but also in regard to building material, including stone, lime and timber—and whatever else may tend to call attention to, and invite the investment of active capital in Indiana.

The only purpose this survey could have served was to focus the attention of politicians and capitalists alike on the yet unstudied and undeveloped mineral wealth of the State.

The fact that the State Legislature did not supply the mandate or the money for Brown's survey is the reason why current Indiana Geological Survey personnel (Patton, 1987) do not regard Dr. Brown as officially having been "State Geologist". However, if the Governor points a finger at you and asks you to do a geological survey of the State, paid for by the State, for the benefit of the State, and at a time when no one else is doing any State-sponsored geologic work, why can't you call yourself State Geologist? Actually, Brown never referred to himself as such; he either may have been told not to use the title or, perhaps, had the wisdom to avoid it, so as not to insult the members of the Legislature. Six biographers have, however, claimed that he *was* State Geologist (Barnhart, 1965; C. Brown, 1927; Collett, 1882; Kemper, 1911; Nowland, 1877; Smart, 1876); after all, a State Geologist by any other name still conducts a geological survey of the State. In fact, several later State Geologists had high regard for Dr. Brown. W.S. Blatchley said (1916, p. 123): "Dr. Ryland T. Brown appears to have been the leader in geological and scientific work in the State during that period [1862-65]." Dunn (1910), probably by personal communication, reported that: "State Geologist Barrett considers him 'one of the ablest-all round scientists that Indiana ever had', and ranks him with David Dale Owen and E.T. Cox in establishing the foundations of geological science in Indiana." Brown's grestest testimonial comes from John Collett (1882, p. 4):

> Ryland T. Brown, a pioneer in scientific researches, and *formerly State Geologist,* made a detailed survey of Fountain County with the vigor and energy so characteristic of the man. His habit of close observation, and long experience, have enriched this report with facts and valuable suggestions. (italics ours)

Collett was describing a 74 year old man.

The Legislature evidently was unimpressed, because no action was taken that year. Dr. Brown (Indiana State Board of Agriculture, 1856, p. xiii) tried another approach, offering the following resolution in 1854:

> By Dr. Brown, that a committee of three be appointed to memorialize the Legislature on the importance of a thorough geological survey and mapping of the State, so as to exhibit the geology, topography, mineralogy, soil, timber &c., of every section of land in the State, and solicit that body to make the appropriation necessary to accomplish this object.

Brown now had taken the lead in lobbying for a geological survey; the foregoing quotation is the first of many subsequent petitions to the State Legislature from the Board of Agriculture. Now, however, others were beginning to jump on the bandwagon. In 1857, Hamilton Smith, lawyer for the American Cannel Coal Company and member of the State Legislature from Posey County, published a report on the economics and engineering aspects of coal mining in the Fifth Annual Report of the State Board of Agriculture. Smith pointed out that without detailed study of the coal fields, a great deal of money was spent by the company on exploration shafts and that financial support of such speculative ventures was difficult to obtain.

Dr. Brown by this time was greatly frustrated by the Legislature's unwillingness to provide for a geological survey, and in the same annual report (Brown, 1857, p. 511) demonstrated his contempt for most politicians:

> On a late visit to the manufacturing districts of the East, I frequently alluded to the advantages of our coal field, and urged the policy of investing capital in the enterprise, but was invariably met with the same reply in substance, to-wit 'If you have the coal to create a moving power, in quantities that may be relied upon, as cheap and easy of access as you describe it, your estimates are correct; but in this matter there must be some mistake, for we remember that the Governor of Indiana has repeatedly urged the Legislature to report officially the

> mineral wealth of the State, by a competent geologist, and they have often declined to do so, and we presume that if the State has any advantages of this kind, the Legislature would not be slow in exhibiting them. We think sir, you must be mistaken'. The fallacy of this argument is apparent to all Western men. It presumes that the Legislature of Indiana is acquainted with the economical wants of the State, and capable of providing for them. This is, to say the least, a very violent presumption. The members of our Legislature are commonly selected, not on account of their general intelligence so much as their devotion to their political party—not on account of their character for decision, energy and enterprise, but often because they have no character, and are therefore available.

Such language must not have endeared him to the Legislature; still worse, 1856 was the last year that Joseph Wright was Governor. Wright's legacy, the State Board of Agriculture, would serve the State for more than 100 years, though he did not live to see the Board given the authority to establish the Indiana Geological Survey.

Brown's contribution to the Board of Agriculture was not limited to pestering the State Legislature; he published several useful essays on various topics ranging from converting swampland to farmland, fertilizer requirements of various local soil types, climate and climatic change, and, of course, Indiana geology.

The State Legislature was not the only obstacle to establishing a geological survey; or rather the Legislature felt it had a good reason to refuse. The situation was eloquently summarized by Ignatius Brown (no relation), Secretary of the Board (Indiana State Board of Agriculture, 1858, p. 203):

> Unfortunately for Indiana the mineral wealth which lies beneath her soil is comparatively unknown, and what is still more a subject of regret, this state of affairs is directly due to the indifference of her own citizens, and the questionable economy of her Legislative Assemblies.

Ryland Brown, aware of this problem, quickly changed his tactics. Instead of appealing directly to the Legislature he would appeal to the public (Indiana State Board of Agriculture, 1869, p. xiv):

> Dr. Brown offered the following resolution, which was adopted:
>
> WHEREAS, recommendations have been made from time to time, by this Board, and by the Executive of the State, setting forth the importance of a thorough topographical and geological survey of the State, exhibiting its mineral wealth and agricultural and manufacturing capabilities, AND WHEREAS the Legislature has heretofore excused itself, and avoided action upon the matter by averring that no expression of public sentiment demanding such action had been presented, therefore,
>
> Resolved, That the Secretary of the Board be instructed to prepare a memorial and petition to the Legislature on this

> subject, and transmit the same to county Agriculture Societies, and to persons who will circulate them for signatures, in order that the Legislature may have a public expression on this subject.

Although unprovable, it can be speculated that this resolution may have been the final blow that caused the Legislature to act, even if timidly. In any event, in the following year, 1859, the Legislature authorized another *contract* survey of the State, saying that the State could not, at this time, afford a permanent survey. The Act was passed March 5, 1859, and the report of the "geological reconnaissance" was due by December 15, 1860 (Blatchley, 1916, p. 115). A sum of $5,000 was appropriated for the task.

What was to become the "Second Owen Survey" could just as easily have been the "Second Brown Survey." The Board of Agriculture was responsible for implementation of the survey, and their first job was to find a person to conduct it. Dr. Brown would seem to have been the logical choice, but in 1858 he accepted the Chair of Natural Science at Northwestern Christian College (Butler University), became less active in the State Board of Agriculture, and likely was not going to leave his new position to do another "geological reconnaissance". Only one other person had done a geological survey of Indiana and that was David Dale Owen. Despite the fact that Owen still was working on a survey of Arkansas, the State Board asked if he would resurvey Indiana. Owen agreed and sent his brother Richard into the field as his assistant and surrogate.

Not satisfied with this small victory, the Indiana State Board of Agriculture (1861, p. xiii) pressured the Legislature to continue funding of a geological survey:

> Believing that a thorough exploration of the mineral and other resources of our State is calculated to increase its actual wealth, and to attract settlers and capitalists, we respectfully request your Honorable Body to make additional appropriations for the further prosecution of the geological survey of this State.

AFTER THE CONFLICT

Just as Brown could easily have been chosen State Geologist in 1859 had he not gone to Northwestern Christian College, the 1859 survey could easily have been the start of a permanent survey, if it had not been for one thing—the Civil War. Even if the Legislature had become amenable to funding a permanent survey, it would have died during the war. Dr. Brown, a personal friend of Governor Morton, supported him in his efforts to keep Indiana loyal to the Union (C. Brown, 1927). Richard Owen, now State Geologist after his brother's death, became Commander of Camp Morton, the Prisoner of War camp in Indianapolis.

Brown's activities during the Civil War are difficult to trace. He seems to have been "officially" on the roster of Butler University, but there were very few students left to teach. As many cutbacks were made at the college during the war, Brown may not have had much of a job. His daughter, Caroline, says (C. Brown, 1927) that he preached and returned to medical practice at this time. In 1864, Brown even organized an insurance company, "The Farmers and Mechanics," and served as president. The venture folded in 1867.

After the war, he evidently returned to teaching at Butler, as Harvey W. Wiley (1916) had joined the staff in 1868 and recalled Brown as being:

> ...a type of many sided man. A preacher of great renown and power, he at the same time was a devoted student of the sciences as they were known and taught in his day. He was particularly a geologist and taught geology by modern methods. ...I joined on more than one occasion his geological excursions with great pleasure and benefit.

Richard Owen returned from the war to become the head of Natural Sciences at Indiana University. He also retained the title of State Geologist, as that position had been made a part of the university in 1861 (Kemper, 1911, p. 12), but he did not have an agency to go along with his title. In 1868, Brown produced a pamphlet entitled *Indiana and her resources* at the request of Governor Conrad Baker (Blatchley, 1916, p. 123). It is interesting to note that while Richard Owen was State Geologist, it was Dr. Brown who Governor Baker asked to produce this pamphlet.

The following year the State Legislature finally authorized a permanent geological survey. It again was placed under supervision of the State Board of Agriculture, and again it was one of their own members, E.T. Cox, who was named State Geologist. Cox had been trained by, and was assistant to, David Dale Owen. A question that might be raised is: among the many field assistants Cox chose, why was Dr. Brown never one of them?

Brown became Professor of Chemistry, and President of the Faculty, at the Indiana Medical College while still teaching at Butler (Nowland, 1877). This double duty lasted two years, until he was appointed by President Garfield in 1871 as Chief Chemist for the U.S. Department of Agriculture in Washington (C. Brown, 1927).

If Brown not only taught geology by modern methods, he had to deal as well with very modern geological problems. In his report to the Commissioner of the U.S.D.A. in 1872, Brown discusses the problem of "the wastes of cities and towns", a subject of great concern, that had been referred to his department. As a doctor, the health risks were obvious (Brown, 1872b, p. 146):

> There is but little doubt that the plague which in other years desolated the great cities of the world—'the pestilence that walketh in darkness'—was really nothing more than the legitimate result of an utter disregard of cleanliness and other sanitary conditions.

Brown viewed the problem in a different light. He saw the problem as resulting from an imbalance in nature; vast amounts of food were grown from the soil, taken to the cities, consumed and dumped as raw sewage into the rivers. Nothing was returned to the soil, and Brown viewed exhaustion of the soil as an equally great disaster. His solution was thoroughly modern—recycle. Returning the sewage to the land as fertilizer would solve both problems. He discussed several ways to accomplish this, although he recognized that many difficult problems remained to be solved.

It is not clear why Brown left the U.S.D.A., but in 1873 he did leave, either due to illness (Nowland, 1877; Smart, 1876), or simply because he grew tired of the desk (C. Brown, 1927). It was H.W. Wiley who took over Brown's job, perhaps at Brown's recommendation.

Returning to Indianapolis, Brown did not lack a means of support. His textbook on physiology, published in 1872, was being used in the schools (Brown, 1872a), and he became City Gas Inspector, replacing State Geologist E.T. Cox! Brown also had his medical practice, preaching, and occasionally was medical pathologist for the State in cases of suspected murder by poison (C. Brown, 1927). In 1874, he returned to the Indiana Medical College as Professor of Chemistry (Nowland, 1877).

Ryland Brown's list of acquaintances was not restricted to ranking politicians of the State. At the Centennial Exposition in Philadelphia, he encountered one morning a stranger who was quite interested in the native woods of the U.S. and their uses; especially hickory. He and Brown discussed matters at length, and they became friends. The stranger later introduced himself as Dom Pedro II, Emperor of Brazil (C. Brown, 1927).

COLLETT AND COUNTY REPORTS

Brown's later geological contributions were under the aegis of the then-current version of a State Geological Survey with John Collett as State Geologist. By Act of April 14, 1881, the State Assembly established a Department of Geology and Natural History "...for the purpose of continuing the geological and scientific survey of this State", and allocated $5,000 for each of the next two years. Amongst the duties of the State Geologist was to "...continue the geological survey of the State, by counties or districts..." (Collett, 1882, p. 5).

John Collett previously was Assistant State Geologist to Edward T. Cox. Cox, who held the post as State Geologist from 1869 to 1880, was the last of the New Harmony group, having served David Dale Owen during the surveys of the Mississippi Valley for the United States government. Most significantly, Collett was also a Wabash College graduate (A.B. 1847, A.M. 1850); thus he was a student contemporary of and likely well-acquainted with Brown. Clearly, their relations must have been good.

Twenty years ago, the present senior author was very hard on Dr. Brown in stating (Melhorn, 1967, p. 106) that "...the 1882 report on...Fountain County is little more than a travelogue and was...almost worthless even at time of publication." Either Brown has improved greatly in 20 years, or there has been an amazing maturation of this writer! For example, Brown's map (1882, p. 92) and descriptions show, for the first time in Indiana, "buried valleys" cut into "subcarboniferous" and "Coal Measure" rocks, and subsequently refilled with glacial deposits:

> This glacial valley shows a depth of 100 to 130 feet as ascertained by several borings along its line. It is now filled with sand, clay and fine gravel... This was probably an ancient bed of the Wabash river, which became obstructed at the glacial period, and the river forming for itself a new channel, this was filled with transported materials.

Brown also described a smaller, similar, glacially filled valley farther south; the general courses of these northeast-southwest striking valleys appear on the frontispiece map. Careful and meaningful correlation from coal borings was required to identify these valleys, and indicate that Brown was no stratigraphic lightweight.

A section headed "Medical Topography" (Brown, 1882, p. 94) is a somewhat remarkable review of settlement history, land clearance, flooding, and drainage, and further relates the correlation between incidence and type of disease (malaria, milk silkness, etc.) and the local elevation, soils, and geological parent materials. Though crude by present standards, this discourse is a pioneering essay on the role of geology in public health.

Other county reports followed in quick succession. Because Marion County, next in line, was sparse in rock outcrop and, unlike Fountain County, lacked any coal or other currently significant mineral resources—the immense gravel deposits along White River, and shallowly buried limestone beds would not become important assets until later—Brown rightly concentrated his efforts on a description of the glacial drift. The reality of the Ice Age was by now generally accepted, but the concept of multiple glaciation was still only dimly perceived (though Frank Bradley had hinted at this matter in 1869). The beginnings of formal nomenclature and relative age dating of drift sequences was a decade in the future. Even the concept of correlation by lateral tracing of identifiable units within the "drift formation" was not commonly practiced. Thus, Brown's establishment (1883, p. 85) of a crude stratigraphy of glacial units beneath Marion County takes on special significance:

> These drift fields present problems...much more difficult of solution than are those of the older rocks; but these great plains of the West will furnish the means of solving these problems, if they are ever to be solved. Elsewhere...drift, therefore, is local, both in its origin and in its deposition; but the drift that covers our great western plain is foreign in its character and general in its deposition. Moreover, it is not a *promiscuous* deposit of clay, sand, water-worn pebbles and bowlders, as the eastern geologists describe their glacial drift to be...Indeed, the drift of Marion County, as we have studied it, has nearly as much regularity and order as we generally find in the stratified rocks.

Brown then proceeds to establish a stratified, regular sequence for the "glacial formation." At the base, resting on bedrock, is coarse gravel, three to six feet thick, overlain by "a heavy member of a very compact, lead colored clay, with but few bowlders." This clay may contain a few, non-uniform, thin deposits of very fine gray or yellow sand; locally, the lower gravel is absent and the clay rests directly on country rock. Elsewhere, at the base of the clay, "several wells...have exposed logs, from ten to fifteen inches in diameter, in a good state of preservation. These are not broken or crushed...". Capping the clay is a few feet of coarse sand or fine gravel, on which rests 20 or 30 feet of "a true glacial drift, having the promiscuous character of the glacial drift described by the eastern writers on this subject."

One must be careful not to read too much into these descriptions, but it is clear that Brown differentiated his "true glacial drift"—today's meltout till or ablation till—from the "lead colored clay" of differing properties, which lay below. It seems equally clear that Brown recognized that this lower unit, which lacked the stones and bowlders of the "true drift," also had been deposited differently, and in considering this problem R.T. entered upon a rambling, confusing discourse, which can best be summed by saying that Brown apparently believed the properties suggested that the clay was deposited "only from very quiet waters, and its compactness and solidity attest the pressure of deep waters." Thus, Brown seems to have envisioned a proglacial lacustrine, perhaps even marine, environment; today, we would probably classify this deposit as basal or lodgement till, deposited beneath an ice sheet and consolidated by ice pressure.

Brown was a prophet in one respect. The "great plains of the West" have and will furnish the means of solving the mysteries of the "drift field" if, indeed, they are ever solved, for a century later we still work on these problems, almost as confused as ever. And for all this, Brown was paid $200 as "Field Work Assistant" from the account of the State Geologist, by vouchers of October 31, 1882, and November 9, 1882.

In addition, Brown was still immersed in medical geology and waxes eloquent in the Marion County report on the importance of the basal clay as a filter which prevents contaminants from houses, stables, and barns from reaching the "inexhaustible supply of very pure water in the gravel and bowlders beneath it", and further (Brown, 1883, pp. 89, 94):

> The surface water, from rains and melting snows, is rapidly absorbed by the porous loam, and...suggests the possibility that it may contaminate the water of a well even twenty feet deep; and...If this be true of country places...how shall we escape the contamination of our superficial wells in a city saturated as Indianapolis is?
>
> There are many places where the upper bed of water-bearing sand is from twenty-five to thirty feet below the surface, and the clay above it is hard and compact. Here a tubed well will provide water of a fair degree of purity; but in an open well it is almost impossible to exclude surface-water when the soil becomes saturated. It will leak in and pass down behind the well unobserved.

THE FINAL REPORTS

Brown's last county reports for the Collett survey are workmanlike but generally of minor significance. The report on Morgan County (Brown, 1884a) is relatively mundane, but does recognize the former existence of what today is called Glacial Lake Eminence, in the northwestern part of the county; recounts the origin of the well-known "lost hill" in White River valley south of Martinsville; and describes the 1850 "gold rush" to the black sand-filled ravines, speculating that "the only rational solution...refers the origin [of the gold] to the blue clay, which is the lowest member of the drift", recognizing that underlying rocks contain no "trap dykes, quartz veins, or other geological disturbances" (Brown, 1884a,

p. 81). Brown was paid $75 on December 1, 1883 for conduct of the Morgan County survey.

The penultimate reports on Hamilton and Madison Counties, for which R.T. received $85 on October 4, 1883, appear as a single package in 1884 (Brown, 1884b). The format follows that of earlier reports, including the usual interesting sections on settlement history, topography, drainage, and archaeological works. By now, Brown was returning to familiar ground; he had covered this territory during the 1854 survey and thus makes herein the only allusion, in any of the Collett volumes, to his earlier work. In discussing the occurrence and tracing of the Pendleton Sandstone across Madison County, Brown (1884b, p. 34) notes: "In 1854, in attempting to trace the outlines of the several formations comprised in the geology of Indiana, I followed the outcrop of this peculiar sandstone..."

The final study, of Hancock County (Brown, 1886) is as uninspired as the geology of the county was undistinguished. As Brown noted: "The underlying rocks nowhere appear on the surface...nor do any of the streams cut deep enough to expose them", and "...the Glacial Drift...is probably very deep, but we could learn of no borings that had measured the thickness at any point...". The erstwhile blue clay Brown now called "till," and he placed increased importance on a discussion of the use of gravel deposits in road construction. It seems that Ryland was staying up-to-date with scientific terminology and changing needs. There also is the customary panegyric about medical geology as related to soils and contaminated water supplies.

By now Ryland Brown was 77 years old and would do no more geological studies. Besides, Maurice Thompson had succeeded Collett as State Geologist; there was a new corps of geological assistants, and Brown was not among them. Perhaps the termination was by mutual consent. Brown continued preaching on a regular basis—he never really had given this up—giving his last sermon on Easter Sunday, a week before he died in Indianapolis on May 3, 1890 from "grip, which he observed for the most part affected the nervous system" (C. Brown, 1927).

FINALE

Why does Ryland T. Brown merit memorialization as one of Indiana's most important geological figures? It is not because R.T. was neither unrecognized nor unappreciated by some of his contemporaries, by later geologists, or by historians; ample proof is cited elsewhere in this paper.

Brown's 1853-1854 geological survey report for the State Board of Agriculture is, in itself, not especially impressive, but one should remember that constraints of time and money, as well as an uncertainty about his precise charge, would not be expected to culminate in some magnificent *tour de force*. Likewise, some of Brown's county reports for the Collett Survey are unspectacular, although clearly the reports on Fountain County and Marion County rank very favorably with other geological reports of the day. Perhaps, Brown's greatest contribution was his persistence on an almost lonely mission—except as abetted by Governor Wright—of establishing a permanent Geological Survey in Indiana, a mission that took nearly two decades to achieve. Also, there is a clear need for recognition of the fact that Brown was an early "environmental geologist," a century before this title came into vogue. The repeated studies of soils and drainage, as related to disease and contaminated water supplies, indicate that R.T. merits this much belated recognition.

One cannot ignore the semantic argument about whether Brown was ever "State Geologist." David Dale Owen called himself "Geologist of the State" in 1839, because the enabling act for this contract survey used those words. Brown, for reasons herein noted, took the title "Geological Agent" (to the State Board of Agriculture); not until the Legislature gave Richard Owen the title "State Geologist," while completing the second Owen "contract survey" in 1862, is the name legitimately used. Despite arguments to the contrary, Brown served precisely the same role as the Owens and was called "State Geologist" by many biographers. There the matter rests.

And finally, in the Analecta of this paper, the still-unanswered question was asked: "Why was Brown seemingly ignored by the Owen brothers?" For that matter, when Cox assumed the title of State Geologist in 1869, why did he not immediately appoint Brown as an assistant? Assuredly R.T. was as qualified as anyone available. Was Brown asked, but decided instead to pursue a presumably more glamorous and rewarding role with the Indiana Medical College? Or did Cox, as the last of the New Harmony group, merely ignore Brown, as apparently the Owens had done? Probably we will never know the answer.

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1987—SESQUICENTENNIAL OF GEOLOGY IN INDIANA

John Barratt Patton
Department of Geology
Indiana University
Bloomington, Indiana 47405

FOREWORD

The following pages contain, more or less, the text of a colloquium lecture given in the Department of Geology, Indiana University, on April 28, 1986. The occasion was the presentation of one of the Richard Owen Awards, established this year and to be a continuing series, to commemorate the centennial year of the degree program in geology at Indiana University.

It is my feeling that many lectures do not make good published papers, or *vice versa*, and surely this one is no exception, as its oral presentation depended heavily upon the use of 71 slides, most of which could not have been reproduced satisfactorily in the medium used here. Despite misgivings on this score, I acceded to requests for copies of the lecture text, which is not to be regarded as a publication, lacking as it does proper citations of sources. Acknowledgment is due and here accorded to W.S. Blatchley for much helpful information that he provided in a paper entitled "A Century of Geology in Indiana" published in the *Proceedings of the Indiana Academy of Science* for 1916 and to W.B. Hendrickson for his 1943 volume *David Dale Owen, Pioneer Geologist of the Midwest,* Indiana Historical Collections, volume 27. Various passages are excerpted or modified from three papers that I prepared earlier.

In designating 1987 as the sesquicentennial anniversary for the beginning of geologic work in Indiana, I was somewhat concerned by the fact that Willis S. Blatchley, State Geologist 80 years ago and a person for whose accomplishments I have deep respect, was author of an article published in the *Proceedings for 1916 of the Indiana Academy of Science* entitled "A Century of Geology in Indiana." Even a person as little inclined toward mathematical approaches as I am known to be recognizes that the century preceding 1916 goes back nearly to the early 1800s, and I set out to determine what early geologic work Blatchley had in mind. These turned out to be William Maclure's 1809 and 1818 maps of the then United States; a description, largely non-geologic, of Wyandotte Cave; and topographic reconnaissance, not mapping, for canals, railroads, and turnpikes. I was comforted by Blatchley's words: "prior to 1837 there is but little record of work done toward utilizing the mineral resources or determining the geology of Indiana".

In that year, an act approved by the Indiana legislature on February 6 began:

> Be it enacted by the General Assembly of the State of Indiana, That the Governor be and is hereby authorized and required annually hereafter to appoint and commission a person of talents, integrity, and suitable scientific acquirements as Geologist for the State of Indiana, who shall receive in consideration of his faithful performance of his duties an annual

> salary not exceeding $1500.00 and necessary expenses not to exceed $250.00, to be paid as the salaries of other civil officers of the State.

Where to find a person of talents, integrity, and suitable scientific acquirements in any sparsely populated frontier State of the time might well have proved to be a problem, but Indiana was the home of a person so well fitted for the role that we must wonder whether the position was not created to utilize his talents. The man was David Dale Owen, one of the sons of Robert Owen, who had purchased the town of New Harmony on the Wabash River in Posey County in 1824.

New Harmony had been established in 1814 by a group of German extraction led by a man named George Rapp. They moved from a colony named Harmonie in Pennsylvania, and numerous letters written by them from the new Indiana settlement are datelined Harmonie, Indiana. It has been reported that Robert Owen changed the name to New Harmony when he acquired it, but a letter of 1815 from George Rapp to his son Frederick is datelined "Neu Harmony" using the German spelling "Neu" and ending the word "Harmony" with "y" instead of "ie". The Harmonists, during their 10 years, made no geologic contribution, but they built a physical base of operations in a wilderness, which their successors probably could not and surely would not have done. When Robert Owen, who was a successful industrialist and progressive thinker in New Lanark, Scotland, sought a site in America to test his ideas for social reform, the ready-made community of New Harmony was for sale and was purchased.

And how did it happen that David Dale Owen, as well as his brother Richard, became geologists? Surely, we must attribute the circumstance in considerable part to the aforementioned William Maclure, a Scot who in 1825 had become a partner with Robert Owen in the ownershp of New Harmony.

Self-trained in geology, Maclure accumulated a fortune in business at an early age and was then able to devote years to his avocations, geology and applied public education, with such success that he has been referred to as the father of American geology and the William Smith of America. The first chapter of Merrill's volume, *The First 100 Years of American Geology,* is entitled "The Maclurian Era, 1785-1819".

Maclure's reputation was established before he came permanently to North America; his geologic investigations and publications in this country, including some of the first regional maps showing the eastern portion of the continent, added to his luster, but this work preceded his investment in New Harmony. In fact, some of it preceded the establishment, under Father George Rapp, of the Harmonists' colony there. Maclure's maps of 1809, before New Harmony was established, and 1818, after the founding of the Harmonist colony, show surficial rocks in Indiana and Illinois Territory to be Secondary, equating in modern terms to Paleozoic and Mesozoic and implying sedimentary origin. He continued to publish, mostly on topics of global scale, through 1832, but his work did not emphasize the geology of Midwestern North America, although the last two of his American papers were published in New Harmony.

It was Maclure, without doubt, who attracted other eminent geologists to New Harmony and gave the New Harmony cultural and scientific movement a geologic flavor that was unique in the New World. The most lasting impact that Maclure had on American geology may well have been the inspiration that he afforded to the then-young David Dale Owen, a person of great talent but without specific direction of interest until about 1835, after Maclure's departure from New Harmony. Maclure himself, his immense collections, and the eminent scientists that he attracted to New Harmony, must have been major factors in Owen's decision to become a geologist. For this purpose he entered medical school at Cincinnati and received the M.D. degree, apparently with no intent of becoming a practicing physician but because he regarded medical training as the best method of filling the gaps in his scientific knowledge. He had already some expertise in chemistry, and he thought it necessary to master physiology and anatomy in order to work with the fossils that were the key to decipering the geologic record in the Midwest. In 1836, apparently between sessions of his medical training, Owen assisted Dr. Gerard Troost, then State Geologist of Tennessee, in a survey of that State. Troost, a Hollander, had spent a period in New Harmony during 1825 to 1827, when Maclure was there.

In the course of horseback traverses in 1837, Owen determined the stratigraphic succession of the bedrock and accurately placed the units in relation to the time scale that was evolving for systemic nomenclature in Great Britain. He correctly separated the systems that later became in America the Mississippian and Pennsylvanian, and he distinguished between the rocks that form the present-day Ordovician and Silurian Systems, even though the Ordovician System was not proposed by Lapworth until 1879. To accompany his report, Owen prepared in 1838 an outline map of the geology of Indiana that was never published but was deposited in the State Library, from which it must have been lost or taken shortly afterward, as I am aware of no reference to it except Owen's own in which he described the map in sufficient detail to establish the fact that the boundaries shown must have been essentially the same as those shown on a map printed in 1846 as part of an Owen paper published in England. To tie the European and American continents together stratigraphically, carrying on precedents set by Maclure and Samuel George Morton, may not seem today to have been a notable accomplishment, but we are speaking of an era in which much of the stratigraphic work was done in a manner that did not offer any correlation of the rocks described with strata elsewhere. Stratigraphic units were most commonly named at the time by their lithologic characteristics, and Owen's were no exception, but their boundaries accorded with those of the classical British systems. His coal formation was the equivalent of the Upper Carboniferous of Great Britain, now the Pennsylvanian System in North America. The map correctly separated the British Lower Carboniferous that became our present Mississippian System and the Devonian and Silurian Systems of the time. A boundary line that encircled the crest of the Cincinnati Arch delineated the then Lower Silurian that became the Ordovician System. In establishing the time relationship of these units with the classical British type sections, Owen extended traditional stratigraphic treatment into a region more than 6,000 miles from the home base and thus furthered the concept of global chronostratigraphy.

The Fenton and Fenton volume, *Giants of Geology*, commented unfavorably upon the tendency for geologists of that time to restrict their interests to the collection and identification of fossils, but they quoted from the first Owen report as follows:

> I have considered it my duty, while surveying a country so new as ours, to remember, that a State just settling, is like a

> young man starting in life, whom it behooves to secure to himself a competency, before he indulges in unproductive fancies. I have considered it the most important object, to search out the hidden resources of the State, and open new fields of enterprise to her citizens. That object effected, time enough will remain to institute inquiries (which a liberal policy, forbids us to overlook) of a less productive and more abstract character; inquiries which are interesting in a scientific, rather than a commercial, point of view.

The Fentons continued "a sane as well as practical rule, and one which made the man who framed it America's first great economic geologist."

Owen correctly predicted that commercial coal would not be found beneath the uppermost of the limestones that are now classified as Mississippian in age. He called attention to both limestone and sandstone suitable for building stone, to clays and shales usable for ceramic ware, to natural cement rock, to iron ores that would suffice for the small-scale recovery operations of that day, to rock units that could be fashioned into whetstones and rotary grindstones, and to sand and gravel deposits. Owen did not actually discover all of these mineral resources, as most had already been noted and used, but he placed the materials into a geologic order that permitted a scientific approach to their location.

As to the prospect for discovery of certain other types of mineral deposits, Owen observed:

> None of the precious metals will ever be found in Indiana unless in minute portion in boulders...

and

> It is not likely that anthracite coal will ever be found in Indiana...

The Owen survey failed to mention only two of the resources that have contributed in any substantial measure to the mineral economy of the State during the ensuring 144 years, petroleum—and we should remember that his work preceded the drilling of the Drake well at Titusville, Pennsylvania, by more than 20 years—and gypsum, which does not appear at the surface and was not discovered until the 1950s.

Political support was strong for continuation of the Indiana survey, but the opposition was strong also. Not until two days before the end of the 1939 legislative session was a bill for continuation approved, and it was amended to cover only 1 year instead of the proposed 3 years. Although the bill passed in February 1839, the Governor did not immediately appoint Owen for continued service, an action that has been attributed, inconclusively, to political rivalry between the then Governor and David Dale Owen's brother Robert Dale. Whatever the cause, reappointment was not offered until June, and by then David Dale Owen had become interested in, and was fairly assured of receiving, appointment as a geologist for the Federal Government. He declined the Indiana appointment. State-supported geological investigations in Indiana virtually ceased for a period of 20 years.

Certainly the geologic activities of David Dale Owen and a number of his professional colleagues, including his brother Richard, did not cease, but most of them did not concern Indiana geology. The new federal appointment was as principal agent to explore the mineral lands of the United States beginning July 31, 1839. Since 1807 it had been the policy of Congress not to sell, but to lease, public lands that contained mineral resources, and in order to make either disposition of federal lands in the lead-bearing region of Galena, Illinois, Dubuque, Iowa, and Mineral Point, Wisconsin, it was necessary to have a geologic appraisal. The House of Representatives called upon the President to communicate to Congress all the information in possession of the Treasury Department relative to the "location, value, productiveness, and occupancy of public mineral lands," and to cause such further information to be collected and surveys to be made as might be necessary. The President, Martin Van Buren, sent the Resolution to the Secretary of the Treasury, who referred it to the Commissioner of the General Land Office. This was James Whitcomb of Indiana, who turned to fellow Hoosier, David Dale Owen, to carry out the work.

Maclure had died in Mexico in 1840, and at the request of Maclure's heirs, Owen spent some time classifying the huge Maclure collection, to which he added many items from his own field work. He made a lengthy collecting trip along the Ohio River in 1841, and the resulting two tons of material exceeded the capacity of the building he was then using as a laboratory, the second in a series. Maclure's sister then gave him a large building, which had been constructed of sandstone and brick by the Harmonists for use as a granary. He remodelled it extensively, and it came to be known as The Laboratory. It contained storerooms, workrooms, and a large lecture hall, as well as exhibit space. In 1846, the noted British geologist, Sir Charles Lyell, with Lady Lyell were the guests of the Owens, and Sir Charles went into the field to see such features of interest as could be readily reached from New Harmony. Soon afterward, Owen and Joseph Norwood, who later became State Geologist of Illinois, explored central Kentucky, apparently on their own and without other financial backing.

In March 1847, the Congress created two new land districts and provided for their survey and offer for sale. Owen was appointed in April to survey the Chippewa Land District northeast of the Mississippi River and south of Lake Superior. It was an area the size of the State of New York and mostly without settlements or established transportation routes.

In 1854, the Kentucky Assembly approved a geological survey of that State, and the Governor selected Owen to head it. In 1857, the Governor of Arkansas offered Owen appointment as State Geologist for a first survey of that State, and Owen accepted the appointment, after arranging with the Governor of Kentucky to continue direction of the Kentucky survey without salary. The first report of the Arkansas survey, covering the years, 1857 and 1858, was published in 1858, at a time when the fourth, and last, of Owen's Kentucky reports was still in preparation.

During the years of Owen's involvement in surveys of the territories and of Kentucky and Arkansas, efforts had continued to resume State-supported geologic work in Indiana. These efforts were successful in 1859, when the General Assembly approved a Geological Survey under the supervision of the State Board of Agriculture. The board wished no one but Owen to supervise the work, and Owen accepted the assignment with the provision that his brother Richard would begin the study and pursue it until the Arkansas survey was completed. Richard Owen conducted a 65-day field season beginning in September and returned to New Harmony with 1,000 pounds of specimens. David Dale Owen reported to the State Board of Agriculture in Indianapolis in January 1860 on the progress of the work and plans for the following season, during which Richard Owen concentrated principally on the Coal Measures.

David Dale Owen had in the meantime further complicated his life by undertaking the construction of a new laboratory in New Harmony to replace the old granary. He designed every aspect of it and supervised the construction. Since the 1854 field season in Kentucky, he had been in poor health from constant bouts with some fever, and to these miseries were added those of acute rheumatism in October 1860. His biographer, W.B. Hendrickson, recounted that Owen was bedfast and dictating the second Arkansas report to two secretaries. His personal physician warned him, "Doctor, if you go on thus you will die in a week." Owen's reply was, "I only want 13 days to finish." He continued dictation until three days before his death on November 13, 1860, at the age of 53. J.P. Leslie wrote to James Hall, "Poor Owen is dead, suicide!", which in a sense was true. As Hendrickson observed, "David Dale Owen literally worked himself to death."

The second Indiana survey was completed by Richard Owen (1862), who was appointed State Geologist succeeding his brother. That the report, except for sections credited to Dr. Robert Peter, Prof. Leo Lesquereaux, and Mr. J.P. Leslie, was largely Richard Owen's work is clear, as shown by such entries as a response to an inquiry from Cannelton, Indiana, regarding the durability of sandstone for building:

> The freestone of Edinburgh, Scotland, which has stood for centuries unimpaired in buildings and bridges, is from the Coal Measures. And I may add a large granary, erected at New Harmony forty-five years since by the Germans, is from the higher series of the Coal Measures. It seems as substantial as the first day, except at one place where some salted meat by being piled against it, caused some scaling and crumbling.

Kenneth Owen and I examined, a few years ago, the sandstone in the building and speculated upon its probable source. It seems likely, in view of the transportation facilities of the day, that it came from the locality a short distance below New Harmony on the Wabash, where a ledge of sandstone forms the rapids that permitted the Harmonists to use water power in their mill. Exposures in the adjacent bluff retain no evidence of quarrying, but the stone resembles that used in the building. Whether based on this advice or not, the Mansfield sandstone is prominent in the architecture of Cannelton.

The second Owen survey was funded only for the period 1859-1861. In May of the latter year, legislation made the State Geologist a member of the Indiana University faculty *ex officio* and several published references during the 1860s refer to Richard Owen by that title, although a supporting organization and appropriation did not exist, and he was not paid directly by the State.

On March 5, 1869, the Indiana General Assembly approved:

> An Act providing for a Geological Survey and for the collecting and preserving of a Geological and Mineralogical Cabinet of the Natural History of this State, and Creating the Office of State Geologist, defining his duties, fixing his salary, and appropriating a sufficient sum of money to defray the necessary expenses of said Survey and for the collection and preservation of said Cabinet.

A new organization named the Department of Geology and Natural Science was established under the State Board of Agriculture, and Edward Travers Cox of New Harmony, a former associate of the Owens in various investigations, was named to head it, which he did for ten years, turning out ten annual reports published in seven volumes that contained much information on a wide variety of subjects but in the opinion and words of Blatchley "...contained little that was new or impressive." Blatchley attributed this deficiency to the fact that so many of the individual papers were county reports done by Cox's assistants, with much overlap and repetition of content.

In 1879, legislation replaced the Department of Geology and Natural Science with a Department of Geology and Statistics. The salary of the State Geologist was lowered appreciably, as were the operating funds, and the duties were vastly expanded in nongeologic directions. Cox declined to continue, and John Collett, who had served as an assistant to Cox, was appointed and accepted. The new department lasted only two years, and in 1881, a Department of Geology and Natural History was established. The term of appointment for the State Geologist was increased from two to four years. Collett continued in the position and turned out four annual reports.

And now, some forty-odd years into the 150 that we are reviewing, we have reached that point at which we can say something definite about geologic **education** in Indiana, as distinguished from geologic investigations. At Indiana University, courses that included some geology were taught at least as early as 1853, but, in the fashion of the day, they were termed natural science or natural philosophy. The Rev. Mr. Robert Milligan offered such training during 1853 to 1855, and Theophilus Wylie did so from 1855 until 1861.

Samuel Bannister Hardin's *Indiana University 1820-1904* first listed geology as a subject of instruction in the early term of the senior year for the "regular" course of instruction in 1856. Those students who pursued the "scientific" course for the Bachelor of Science degree also studied geology, but the record does not show whether the instruction was separate or different from that for regular students. During this period, the scientific course occupied three years and the regular course four, the difference being omission of the Ancient Languages. By 1865, it was specified that the geology in the senior year made use of Dana's textbooks. In 1868, the scientific course was lengthened to four years, and the former "regular" course was renamed the "classical" course. It continued to include geology in the final term, as did the scientific course, but the science students at sophomore level were also taking physical geography, which we may suspect to have included physiography.

In 1875, the classical course covered mineralogy and lithological geology at the junior level and paleontology at the senior. The scientific course had mineralogy and lithological geology at the junior level and stratigraphic geology, paleontology, and dynamical geology at the senior.

From the time that Richard Owen was appointed Professor of Natural Philosophy and Chemistry in 1864, we may be sure that geology was included in the instruction. His title was changed to Professor of Natural Science and Chemistry in 1874. Theophilus Wylie's history of Indiana University says that Richard Owen "gave instruction principally in Geology, Mineralogy, and Chemistry, and during vacancies in the Modern Language Department he taught German and French." Professor Harry Day, in a paper presented last year at the Indiana Academy of Science, said "...Owen was the first teacher of chemistry, physics, or geology at Indiana University to publish scientific papers." With Owen's retirement in 1879, such geologic instruction as was given, so far as we can determine, was offered by David Starr Jordan.

David Dale Owen's famed collection of 85,000 specimens was acquired by the University in the 1860s. It was lost, along with the University's library and administrative records and all scientific equipment and supplies, in 1883, when the Science Building burned. The loss was responsible for the decision to move the University from the location that it had occupied since its establishment in 1820, five blocks south of the Courthouse Square, to a new one five blocks east of the Courthouse. There, the Board of Trustees purchased a 20-acre tract known as Dunn's Woods, a part of the Dunn farm. Contracts were let and construction started in 1884 for the two first buildings, Owen and Wylie Halls, both to be important to the Department of Geology and the Geological Survey. Owen Hall was named in honor of Richard, David Dale, and Robert Dale Owen, Wylie Hall for Andrew Wylie, the first President of Indiana University, and for Theophilus Wylie, then Professor of Physics.

The year 1886 heralded introduction of the major subject system, and one of the courses of study leading to the B.S. degree was in Biology and Geology. Such dual or multiple designations were accompanied by liberalization of an elective system that had begun in 1868, although then affecting only languages. For some years after 1886, geology was one of the elective subjects that satisfied a science requirement for the A.B. degree.

In April 1885, the Board of Trustees had created a Chair of Botany and Geology, and a Department of Geology was established for the 1885-1886 academic year with the appointment of John Casper Branner as Professor of Geology, Instructor in Botany, Curator of the Museum. Three courses were listed, and a geology laboratory and museum were set up on the second floor of newly completed Owen Hall.

To return our attention now to the Geological Survey, Cox and Collett had been dutifully listed as faculty members *ex officio* in the University catalogs without, so far as I can determine, having any involvement with the academic program. Collett had been appointed to a 2-year term by a governor who was a Democrat and a 4-year term by the next governor, who was a Republican. A Democrat was elected governor in 1884, and, apparently unsuccessful in finding a qualified geologist in his own party, appointed Maurice Thompson, who was a civil engineer and a successful author of fiction. He served only three years, from 1885 to 1888. Two annual reports were issued during his tenure, and their geologic high points were new information concerning the thickness and character of the glacial drift, a confused misunderstanding on the part of both S.S. Gorby and Thompson of the Niagaran reefs at the surface in northern Indiana, and the first accounts of the discovery of natural gas.

Thompson resigned before his term was completed but after the election of 1888, and the outgoing governor appointed S.S. Gorby to fill the position. The new governor was a Republican, but the legislature remained firmly in the hands of the Democrats, and they set out to remove as much as possible of the governor's authority. A bill, passed over the governor's veto, abolished the Department of Geology and Natural History and the appointive office of State Geologist connected therewith and established a new Department of Geology and Natural Resources, to be headed by a Director **elected by the General Assembly.** The legislature then appointed (not elected) Gorby State Geologist. The new governor refused to recognize the act, and in March of 1889, he appointed Collett to the post. Gorby declined to give up the office, and Collett apparently did not press the issue. In November, the Supreme Court held that the legislature had no power to create an office and then fill it; the choice must be made by the governor or by popular election. Gorby managed to hold on until 1890, when he was nominated by the Democrats and won the election. His six years in office were more notable politically than geologically.

The sixth State Geologist of Indiana, Willis Stanley Blatchley, was, in my judgement, the greatest builder of program strength during the first century of the period covered by this study. He served from 1895 to 1910—longer than any of his predecessors. Time in office is surely a factor in establishing a program, but from the beginning of his tenure he demonstrated an unusual ability to identify and attract capable scientists, either to work for his organization or to publish the results of their investigations in the annual reports without being paid. The authors of the papers in annual reports issued during the Blatchley years constitute a merit list in geology. To avoid comparison and unintentional ranking, I list a few of them in alphabetical other: George Ashley, one of the first and greatest coal geologists; E.R. Cumings (to be mentioned further in this paper); August Foerste, the sage of the Silurian; T.C. Hopkins, author of valuable reports on the geology of the industrial minerals and a turn-of-the-century sedimentary petrologist before the term was used; E.M. Kindle, stratigrapher and paleontologist in the Silurian and Devonian rocks and bibliographer and cataloguer of literature and fossils; and C.E. Siebenthal, expert on building stones and cement and the geology of the rock units used for both. Blatchley was primarily an entomologist rather an a geologist; he established an enviable record of productivity with meager funds— the sign of an able administrator.

In the election of 1910, Blatchley was defeated by Edward Barrett, who served two 4-year terms during which an increasing proportion of the published work was in the form of county soil surveys. This concluded the period during which the office was elective.

During the latter years of the 19th century and the early part of the 20th, much of geologic interest was accomplished outside the State-supported program and the academic institutions. In the 1880s, A.J. Phinney was the author of various papers in the annual reports of the organization that by then had come to be called the Indiana Department of Geology and Natural History, but Phinney's most notable achievement in Indiana geology was done under the aegis of the

Federal, rather than State, government and published in 1890 by the then relatively new U.S. Geological Survey in its 11th Annual Report. It was the 160-page paper entitled "The Natural Gas Field of Indiana"—one of the earliest and best in the annals of petroleum geology.

We cannot claim any Indiana affiliation for Frank Leverett, but surely he spent much time in Indiana doing geologic work for the United States Geological Survey, and it was in Indiana and other Midwestern States that he conducted much of the field work leading to early precepts of continental glaciation and distribution of glacial materials. His works and maps were published, beginning before 1900, in annual reports and monographs of the U.S. Geological Survey, and for Monograph 53, his co-worker and co-author was Frank B. Taylor, who was a native of Fort Wayne. The Laverett and Taylor manner of depicting glacial geology was notable in lending pattern and reason to the materials and to the events responsible for their distribution.

Frank Taylor has received less recognition than might have been expected for proposing, in 1910, some two years before Alfred Wegener, reconsideration of continental drift, which had been suggested much earlier by Francis Bacon in 1620 and Antonio Snider in 1855 without receiving serious attention. Both Taylor and Wegener were impressed by the jigsaw fit but had problems in explaining the mechanism. Wegener became noted for his advocacy and Taylor did not, in part because he lacked a DuToit. Doctor Johnson, it may be argued, would probably have been well recorded in history without Boswell, but Wegener, equally probably, would not have without DuToit, just as Hutton's views might have had much less impact but for Playfair.

During the same turn-of-the-century decades that we have been reviewing, the academic program in geology grew slowly after the Department was established. Branner stayed only six years, and the first graduate of record was Edward M. Kindle, who received the A.B. degree in 1893, by which time Associate Professor Vernon F. Marsters was in charge of the department. Kindle was appointed Instructor for the year 1893-1894, and for the first time, the department had a two-man faculty. John F. Newsom joined the faculty as Instructor in 1894-1895, replacing Kindle. A third faculty member, Edgar R. Cumings, was added as Instructor in Paleontology for the 1897-1898 year, beginning the longest service record in the departmental faculty. Doctor Cumings became head of the department in 1905 and retired as Emeritus Professor in 1944.

The first Master of Arts degree was awarded in 1899 to James Arra Price. The name of the department was changed to Geology and Geography in 1900, but the word geography was dropped from the title in 1904. J.W. Beede became Instructor in 1901-1902.

In 1902, the department moved from Owen Hall to the fourth and fifth floors of the new Science (now Lindley) Hall. The department's first doctoral degree was awarded in 1913 to J.J. Galloway, who was then appointed Instructor. The number of faculty reached four in 1916-1917, when W.N. Logan and C.A. Malott were appointed as Associate Professor and Instructor, respectively (J.J. Galloway had left to join Columbia University at the end of 1915-1916).

Indiana State government underwent massive changes, when a reorganization act was passed early in 1919 and took effect in April of that year. The Indiana Department of Geology and Natural Resources was abolished, and its responsibilities were assigned to a Division of Geology within a newly created Department of Conservation. Because the office of State Geologist was elective, it had to be placed on the ballot in 1918, even though it was virtually certain to terminate. The victor was Louis Roark, who was a new faculty member in the Department of Geology. The office to which he was elected ceased before inauguration. In the new arrangement, the Division heads were appointive, and the governor designated Wm.N. Logan, who had joined the Indiana University faculty with the 1916-1917 academic year, to head the Division of Geology concurrently with his academic duties. With Logan's appointment, there began the closest alliance between the University's Department of Geology and the State program that has ever existed. An office that managed such regulatory matters as drilling permits and plugging of wells continued in Indianapolis, but the office of the State Geologist, as the position continued to be called, was on the Bloomington campus. Faculty members and students carried out most of the investigations, many of them through summer field parties. The annual reports that had been issued for so many years and that had included, in single-volume bound form, all the year's publications, became brief administrative accounts of the year's activities; scientific papers were issued, generally separately, within a numbered Department of Conservation series that included publications from other divisions. An exception was the *Handbook of Indiana Geology* (Pub. 21), which contained six parts and ran to 1120 pages. Included were C.A. Malott's "The Physiography of Indiana," in which he named and described seven bedrock physiographic regions that cover all of southern Indiana south of the Wisconsinan glacial boundary and extend, recognizable from subsurface records, beneath the thickening glacial drift to the north. Doctor Malott preferred to term himself a physiographer rather than a geomorphologist, and I believe that he was correct in doing so. He had the unusual ability to describe terrane in a manner that made it recognizable to persons seeing it for the first time. In the 64 years since Malott named the physiographic units, no changes have been made in their designation, possibly because Malott described them so well. Another part of the *Handbook* is John Robert Reeves' paper, "Preliminary Report on the Oil Shales of Indiana," a work that has received much attention during the past decade of energy concerns.

A final example of the University-State agency cooperative effort to which I refer is the Indiana Department of Conservation Pub. 75—*Geology of the Silurian Rocks of Northern Indiana*, one of a triumvirate of papers by E.R. Cumings, Chairman of the Department of Geology at the time, and Robert R. Shrock, who addressed this audience as the first Owen Award speaker. The three papers were fundamental works on reefs and their environment, and they have joined the ranks of classics. Reef geology, largely neglected during much of the time since Darwin's day, was principally of academic interest at the time of the Cumings and Shrock studies, but its significance to petroleum geology brought it to the forefront in the 1940s.

In describing the relationship between the Geological Survey and the Department of Geology during the 1920s and 1930s, I have mentioned a number of the principal players. The geology faculty was augmented by John R. Reeves and Wm.N. Tucker in 1921, by Arch Addington in 1923, and by Ralph Esarey in 1924. Wm.D. Thornbury was appointed Instructor in Geography in 1927, and J.J. Galloway returned from Columbia University as Professor in 1932. Several of those mentioned were here for only a few years, and the general size of the geology faculty was four or five until the Second World War. With Doctor Logan's retirement after the 1935-1936 academic year, Ralph Esarey became State Geologist and served until 1945.

Life changed considerably, and for the better, for the department and the State Geologist in 1937, when both moved to Owen Hall, this time having the entire building and being very pleased.

Near the end of the Second World War, President Herman B Wells proposed to the Indiana Department of Conservation that the Geological Survey and the Department of Geology be directed by a single head and that the geology faculty constitute most of the professional staff of the Survey. Research Associateships were to be supplied through the Conservation budget, as were funds for field expenses. The search for a new head resulted in the selection of Charles F. Deiss, then head of the Department of Geology at Montana State University at Missoula, to be Chairman and State Geologist. He arrived in 1945 and began immediately to build staff. One of his best expressions was that the unspecified emoluments were the most persuasive in recruiting faculty and professional staff of high quality. By this he meant supportive services of high quality, such as drafting, photography, instrument making, and analytical capabilities. The Geological Survey grew under his direction to a staff of about 50 in a dozen years. Faculty expansion began immediately. Three of the faculty in the combined Department of Geology and Geography were teaching geology in the year before Doctor Deiss was appointed. Geography became a separate department with the 1946-47 academic year, and W.D. Thornbury, who had until then been principally engaged in geographic instruction, remained with the Department of Geology. Faculty size reached a plateau of 11 members by the early 1950s and remained at about that level until the 1960s. The curriculum expanded even more rapidly. Sedimentation, glaciology, and geomorphology appeared in the University catalog in 1946; petrography in 1947; optical mineralogy and sedimentary petrography in 1948; principles of geochemistry in 1949; and problems in applied geophysics in 1950. Field training, which had previously consisted of a local mapping course, was conducted at Red Lodge, Montana, during the summers of 1947 and 1948, and construction of our own Field Station in the Tobacco Root Mountains went on concurrently with the new course Field Geology in the Rocky Mountains in 1949. One of the students in that year's course told me that they ate as much sawdust as food. The rapid expansion of both organizations had posed imperative space needs to which Indiana University responded valiantly. The two organizations were occupying parts or all of 11 buildings when consolidation into the present quarters took place in 1962 for the Department and 1964 for the Survey.

I choose to close the account at this post-war period, being very leery of historic judgement before the episodes and results have seasoned.

As epilogue, we might contemplate how a frontier state established in 1816 turned so early in its history to geology as an aveune to economic progress and a vital part of its system of higher education, and I should say that it was fortuitous rather than a result of planning. That fortuity began on the banks of the Wabash when William Maclure became a partner in the New Harmony venture. George Browning Lockwood, in a 1902 volume named *The New Harmony Communities* commented:

> While the Rappite regime is less interesting, and vastly less important, then the Owenite period, it affords a strong back-

> ground for the later experiments, the failure of George Rapp's success standing out in vivid contrast to the success of Robert Owen's failure.

The Harmonist colony was materially productive, so much so that departure and a new start elsewhere became necessary to preserve their objectives, and their legacy was a material one. The Owen experiment foundered in its formative months, but it left a legacy of science, culture, and education that is identifiable two decades after its sesquicentennial anniversary.

MICROBIOLOGY AND MOLECULAR BIOLOGY

Chair: Carolyn Vann
Department of Biology
Ball State University
Muncie, Indiana 47306

Chair-Elect: Carl E. Warnes
Department of Biology
Ball State University
Muncie, Indiana 47306

ABSTRACTS

The Effects of *In Vivo* Exposure to Ozone on Hamster Tracheas. Dorothy Adalis, Department of Biology, Ball State University, Muncie, IN 47306.—Syrian Golden hamsters were exposed to ozone to determine the effects on the ciliated epithelium of the upper respiratory tract. A variety of times and doses were studied to include 0.25, 0.5, and 1.0 ppm for 1, 3, or 5 days. Quantitative measurements of the cilia beat frequency were determined using a stroboscope and statistically analyzed. Results of *in vivo* exposures to 0.25 ppm and 0.5 ppm ozone indicated a dose related reduction in cilia beat frequency that was statistically significant at the $P < 0.01$ level. A cytopathological assessment was made to determine if ozone alters or interferes with the structural integrity of the ciliated epithelium. The histologic assessment indicated dose-related, adverse pathological effects in the tracheas of hamsters exposed to ozone. The results indicate an altered functioning of the tracheal ciliated epithelium which would possibly interfere with the host's normal pulmonary clearance mechanism.

Construction of a Hybrid Cloning Vector with a Temperature-Regulatable Promoter for *Synechocystis* 6803. In So Bae, Jo Ann Meunier, and Carolyn Vann, Biology Department, Ball State University, Muncie, IN 47306 and Animal Science Dept., The Ohio State University, Wooster, Ohio.—Two hybrid plasmid vectors were constructed which are capable of regulating the expression of cloned genes in both *Escherichia coli* and in the cyanobacterium, *Synechocystis.* Vector pBV1 contains origins of replication for both organisms, an ampicillin resistance gene, a lambda temperature sensitive repressor gene (cI857) to regulate gene expression, and the powerful rightward promoter of bacteriophage lambda to ensure that cloned genes are transcribed at a high level. Vector pTC1 was created by inserting a gene for chloramphenicol resistance (CAT) downstream of the lambda promoter in vector pBV1. The expression of the CAT gene in *E. coli* was quantified spectrophotometrically following the addition of cm and a shift in growth temperature. A 10-fold increase was observed, indicating temperature-regulated expression.

Azole Sensitivity and Hyphal Formation of a Cytochrome P450 Mutant of *Candida albicans*. M. Christine Broughton, Norman D. Lees, and Martin Bard, Indiana University-Purdue University at Indianapolis, Dept. of Biology, 1125 E. 38 St., P.O. Box 647, Indianapolis, IN 46205.—Low concentrations of azole antibiotics inhibit the enzyme 14α-demethylase in yeast. Subsequent accumulation of 14α-methylsterols in the membrane has been reported to result in growth inhibition and lack of hyphae formation. Other demonstrated effects noted at higher drug concentrations involve respiratory inhibition and membrane disruption. Strain D10, a cytochrome P450 demethylase mutant of *C. albicans,* has been shown to be viable on normal media and to be defective in hyphae formation. Addition of three azoles at concentrations of 10, 50, and 100 μM to actively growing cultures of D10 and a wild type revertant, D10R, resulted in immediate growth inhibition of both strains. The viability of D10 demonstrates that the substitution of 14α-methylsterols would not result in complete growth inhibition. Therefore, the fungistatic effect seen clinically may be due to a combination of factors including altered sterols, respiratory inhibition, and inability to form hyphae.

Methylation and Sporangiospore Germination in *Mucor racemosus.* KATHRYN FOSS and J.R. GARCIA, Ball State University, Muncie, In 47306.—A previous study with this dimorphic fungus showed that the specific activity of S-Adenosylmethionine (SAM) Synthetase increased significantly during the aerobic germination of sporangiospores. It was also shown that the addition of cyloleucine prevented both the increase in specific activity and the formation of germ tubes. In the present study we attempt to determine how early, in the germination process, the enzyme is active and the effect of the addition of cycloleucine at different times during germination. Sporangiospores were placed in a semi-defined medium, at 25°C, and samples were taken throughout the time period required for germination. We showed that the enzyme was active even in the dormant sporangiospores. We also showed that the addition of cycloleucine, during the first 4.5 hours, would block the formation of germ tubes. Experiments with cycloleximide showed that *de novo* protein synthesis was necessary throughout the experiment in order for germ tubes to be synthesized. These results suggest that methylation of macromolecules could play a central role in germination.

Site-Directed Mutagenesis of the Manganese Stabilising Protein (MSP) in *Anacystis nidulans* R2. KENNETH FRIMPONG and CAROLYN N. VANN, Department of Biology, Ball State University, Muncie, IN 47306.—Homology analyses and predictive algorithms have been employed to analyse the photosystem II MSP of *A. nidulans R2.* Amino acid homology searches between MSP and six other manganese binding proteins were conducted using the IBI/Pustell Sequence Analyses System (International Biotechnologies, New Haven, Conn.). The entire MSP protein was further analysed using the predictive algorithms of Chou and Fasman (1978), Argos and Palau (1982), Parker and Guo (1986), and Manavalan and Ponnuswamy (1978). The study has elucidated probable manganese-binding residues. Combinatorial, site-directed mutagenesis will be conducted to investigate the information content of the positions of the probable ligands.

Cloning of a Gene Encoding a Mosquitocidal Toxin from *Bacillus thuringiensis* var. *isrealensis.* LEAH M. HELVERING and CAROLYN N. VANN, Ball State University, Muncie, IN 47306.—*Bacillus thuringiensis* var. *isrealensis* (Bti) produces a crystalline endotoxin specific for larvae of mosquitoes that may be vectors of malaria. The gene encoding the endotoxin is being cloned into the cyanobacterium, *Anacystis nidulans* R2, to determine if its level of expression is sufficient for mosquito lethality. A 108kb plasmid from Bti 4Q2-72 has been isolated and digested with XbaI to obtain a 3.8kb fragment that encodes a protein which is part of the crystal endotoxin. This fragment has been cloned into the hybrid cloning vector, pTNTV, and the chimaera transformed into *Escherichia coli.*

Transformants are being screened and the level of toxin expression in *E. coli* and *A. nidulans* will be examined.

Transformation Efficiency and Stability of Two Hybrid Cloning Vectors in *Synechocystis* 6803. KEMP HORKEN and C.N. VANN, Ball State University, Muncie, IN 47306.—Transformation efficiencies of two newly constructed hybrid cloning vectors, pBV1 and pTC1, into the cyanobacterium *Synechocystis* 6803 will be presented. The hybrid vector pBV1 is capable of replicating in both *Escherichia coli* and in the cyanobacterium *S.* 6803. In addition, the vector contains bacteriophage Lambda sequences to allow temperature regulated expression of a cloned gene. Plasmid pTC1 is the vector pBV1 with the reporter chloramphenicol acetyl transferase gene cloned into it. Since previously constructed hybrid vectors have undergone recombination upon transformation, the plasmid pTC1 is also being transformed into a previously transformed strain to determine if this will result in enhanced stability.

New Structural Alleles for Mouse Androgen-Binding Protein (ABP) and a New Gene Capable of Modifying ABP. ROBERT C. KARN, THERESA S. REMPEL, TINA M. WALLS, and STEPHEN R. DLOUHY, Dept. of Biological Sciences, Butler University, Indianapolis, IN 46208.—Mouse salivary androgen binding protein (ABP) is a series of dimers composed of an alpha subunit disulfide-bridged to a beta or a gamma subunit. We have proposed separate genes, *Abpa, Abpb* and *Abpg,* respectively, for the subunits. Genetic data suggest that the *Abpa* and *Abpg* are closely linked on chromosome 7 (Dlouhy, *et al.,* Genetics 115: 535, 1987). ABP phenotypes may be more complex in some mouse salivas due to the presence of the dominant allele, *Ssp*^{S}, of a modifier gene, *Sex-limited saliva pattern* (Karn, *et al.,* Biochem. Genet. 20: 493, 1982) which is not linked to *Abp* (Dlouhy and Karn, Biochem. Genet. 22: 657, 1984). We have studied inbred mouse subspecies determining ABP phenotypes by detection of bound ^{14}C-testosterone and by immunostaining western transfers. Two of these subspecies, IS/CameEi and CAST/Ei, were selected for further study and crossed with C3H/St and with DBA/2J. The F_1 from the IS/CamEi x C3H/St cross, was intercrossed to obtain the F_2. The phenotypes observed in these crosses suggest the presence of a variant of one of the subunit genes in the IS/CamEi strain. Preliminary analyses of CAST/Ei salivas revealed sex-limited phenotypes. The progeny from crosses with C3H/St and with DBA/2J show similar sex-limited variation in F_1 progeny. Backcross data suggest that the CAST/Ei strain has both a unique structural variant of *Abp* and a modifier gene with action different from that of *Ssp*^{S}. We designate the new structural variants seen in CAST/Ei and IS/CamEi as c and d variants of *Abp,* respectively. Studies are underway to determine whether the modifier seen in the CAST/Ei strain is an allele of *Ssp* or a distinct gene.

Molecular Analyses of the Structure of Mouse Submaxillary Androgen-binding Protein (ABP). ROBERT C. KARN and ROSEMARY WOOD, Department of Biological Sciences, Butler University, Indianapolis, IN 46208.—Mouse saliva contains a series of androgen-binding proteins (ABPs) contributed mainly by the submaxillary glands. Molecular weight analyses of ABPs indicate that they are dimers each consisting of a larger (alpha) subunit disulfide-bridged to a smaller (beta or gamma) subunit. Genetic studies suggest that the subunits are determined by distinct genes, a concept supported by the observation of three products of *in vitro* translation. The goal of this study is to isolate cDNAs corresponding to the various ABP subunit mRNAs from a mouse submaxillary library and sequence them in order further to explore the three-gene hypothesis. We purified the alpha subunit and obtained approximately a third of its N-terminal amino acid sequence and then determined about the same portion of the amino acid sequence of the beta subunit by sequencing the dimer and subtracting the alpha sequence. The intact dimer has two free N-termini in equimolar concentrations consistent with our dimer model for ABP. Using the genetic code we obtained a mixed oligomer probe for the alpha subunit and used it to explore sequences in a mouse submaxillary cDNA library. Three clones were selected by this method and grown up for further analysis. Electrophoresis of fragments obtained by *PstI* digestion of the plasmids suggests that the three clones contain cDNA inserts smaller than 1 kb. All three clones were positive on Southern transfer analyses probed with the end-labeled oligomer. Our future work will involve recloning the inserts into the M13 sequencing vector for analysis by the Sanger sequencing method.

Restriction Mapping of a Plasmid from *Bacillus thuringiensis* var. *isrealensis*. SARA L. LITZ and CAROLYN N. VANN, Ball State University, Muncie, IN 47306.—*Bacillus thuringiensis* var. *isrealensis* 4Q2-72 harbors a 108kb plasmid which contains genes responsible for the production of crystalline endotoxins. The plasmid has been isolated and is being randomly restricted to produce fragments of approximately 10kb. Lambda GEM-11 cloning vector will be used in making a genomic library. The endotoxin genes will be identified and the fragments hybridized for the construction of a map. Progress will be reported.

Inhibition of Antibody Formation by Cyclosporine A. ANGELA SCHILKE and NANCY BEHFOROUZ, Ball State University, Muncie, IN 47306.—Cyclosporine A (CsA) is a widely used immunosuppressive drug which has novel, clinically beneficial effects on the immune system. There is substantial evidence that CsA preferentially acts by impairing T cell lymphokine production, but there is some evidence that CsA may also affect B cells and other antigen presenting cells directly. Using an *in vitro* antibody response to SRBC, we have examined the effect CsA has on different populations of mouse lymphocytes. CsA appears to have a profound, early acting inhibitory effect in a dose dependent manner at physiologically achievable level *in vitro* on whole splenocytes from naive animals. Antibody production by B and T cell mixtures could also be inhibited by CsA in a similar manner. T cell lymphokines added to B and T cell cultures could not overcome the CsA induced inhibition. Indeed, populations of highly enriched or positively selected B cells stimulated to produce antibody by antigen and T cell lymphokines are profoundly inhibited by the early addition of CsA. These findings suggest that CsA has direct inhibitory effects on lymphocytes, including B cells, aside from, or in addition to, a reduction of lymphokine production by T cells.

Construction of a Hybrid Cloning Vector with an Iron-Sensitive Promoter. WILLIAM E. SNYDER, JR. and CAROLYN VANN, Biology Dept., Cooper Hall, Ball State Univ., Muncie, IN 47306.—A hybrid cloning vector is being constructed that possesses a promoter that responds to the iron content in the growth media. The vector, pANIC 1, will contain sequences from the resident plasmid, pANS, of *Anacystis nidulans* R2. It will also contain *E. coli* sequences from the pUC 18 vector, enabling it to replicate in either system. The promoter allows for expression of a cloned gene in low iron media. A segment of pKJ110 containing the sequences encoding the promoter were ligated into pUC 18 to form pIC 1. Sequences downstream of the promoter were cleaved out of pIC 1 to form pIC 4, which has the promoter directly upstream from the multicloning site of pUC 18. The final phase of construction is to ligate a segment of pANS into this vector to form pANIC 1. PANIC 1 will be used to study the effects of mutated photosynthesis genes on the photosynthetic processeses in *A. nidulans* R2.

Effect of Toxicants on Chitin Decomposition. CARL E. WARNES, J.A. BALDAUF, and L.M. GARRIOTT, Department of Biology, Ball State University, Muncie, IN 47306.—Highly active chitinolytic isolates from soil and water were examined for sensitivity to varying concentrations of zinc and the pesticide diflubenzuron. Preliminary studies conducted with cell free enzyme preparations showed increased sensitivity when zinc concentrations approached 5 mg/l. Purified chitinase enzyme preparations however showed no sensitivity well beyond the range considered toxic (5 mg/l). Diflubenzuron, on the other hand, did not inhibit cell growth or chitinase production at levels approaching maximum solubility. Chitinase assays conducted in the presence of varying concentrations of diflubenzuron likewise showed no inhibitory response on enzyme activity. Therefore, this insecticide which interferes with chitin deposition through chitin synthetase showed no adverse effect on bacterial chitinase production or activity. Both processes may act cooperatively in the elimination of chitinous pests.

Isolation of Viral RNA from *Cattleya*-Alliance Orchids. PAULA D. WILLIAMS, HERBERT L. SAXON, and CAROLYN VANN, Biology Dept., Muncie, IN 47306.—The two most economicaly important viruses of orchids are Cymbidium Mosaic Virus (CyMV) and Tobacco Mosaic Virus-O Strain (TMV-O). Published research has shown that viral symptoms of both viruses can be attenuated in host plants where previous viral infections have conferred resistance. Plants expressing high copy numbers of virus coat protein genes have a similar resistance to viral infections. The genetic engineering of orchids to express these virus coat proteins presents significant challenges and opportunities. Successful isolation of viral RNA from infected orchids is a necessary early step for expressing high copy numbers of virus coat proteins in transgenic orchids. The speaker reports the results of research to isolate the viral RNA of CyMV from infected Cattleya-alliance orchids.

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A COMPARISON OF TRANSFORMATION EFFICIENCY OF HYBRID CLONING VECTORS pPGV5 AND pTNTV IN THE CYANOBACTERIA *ANACYSTIS NIDULANS* R2 AND *A. NIDULANS* R2SPc

Teri Ann Hicks and Carolyn N. Vann
Department of Biology
Ball State University
Muncie, Indiana 47306

ABSTRACT: In this study, a comparison was made of the transformation efficiencies of two hybrid vectors into the cyanobacteria *Anacystis nidulans* R2 and *A. nidulans* R2SPc. The two vectors were hybrid cloning vectors capable of replication in both strains of *A. nidulans* as well as in *Escherichia coli*. In addition, these vectors contained the powerful bacteriophage lambda promoter sequences for enhanced expression of cloned genes. Plasmid pTNTV was constructed from pPGV5 to create a unique restriction site to facilitate the cloning of DNA fragments into the vector and to create a smaller vector so that the vector with an inserted DNA fragment would be of a reasonable size for transformation. The transformation frequencies obtained using pTNTV were 1.5×10^7 transformants/μg DNA for *A. nidulans* R2 and 6.6×10^6 transformants/μg DNA for *A. nidulans* R2SPc. Thus, the modified vector pTNTV retains the high transformation efficiency of the parent vector pPGV5 but will be a more useful cloning vector as a result of its smaller size and unique cloning site.

INTRODUCTION

Cyanobacteria are prokaryotes that perform oxygenic photosynthesis much like that of eukaryotic plants. They also contain important bacterial properties that allow for easy genetic manipulation. Some of these properties are the existence of indigenous plasmids useful for constructing hybrid cloning vectors, short reproduction time, a small genome, and most importantly, the capability to be transformed.

Transformation is a process that involves genetic modification induced by the assimilation of DNA. In this study, transformations were performed using hybrid cloning vectors that were constructed from plasmids capable of autonomous replication in the cyanobacteria, *Anacystis nidulans* R2 and *A. nidulans* R2SPc. The use of plasmid vectors in transformation is a useful technique in recombinant DNA technology in that it enables researchers to easily alter the genetics of an organism, to enhance the expression of particular genes by increasing the number of gene copies in an organism, to introduce foreign or mutated genes, and to simply recover the introduced DNA by plasmid isolation.

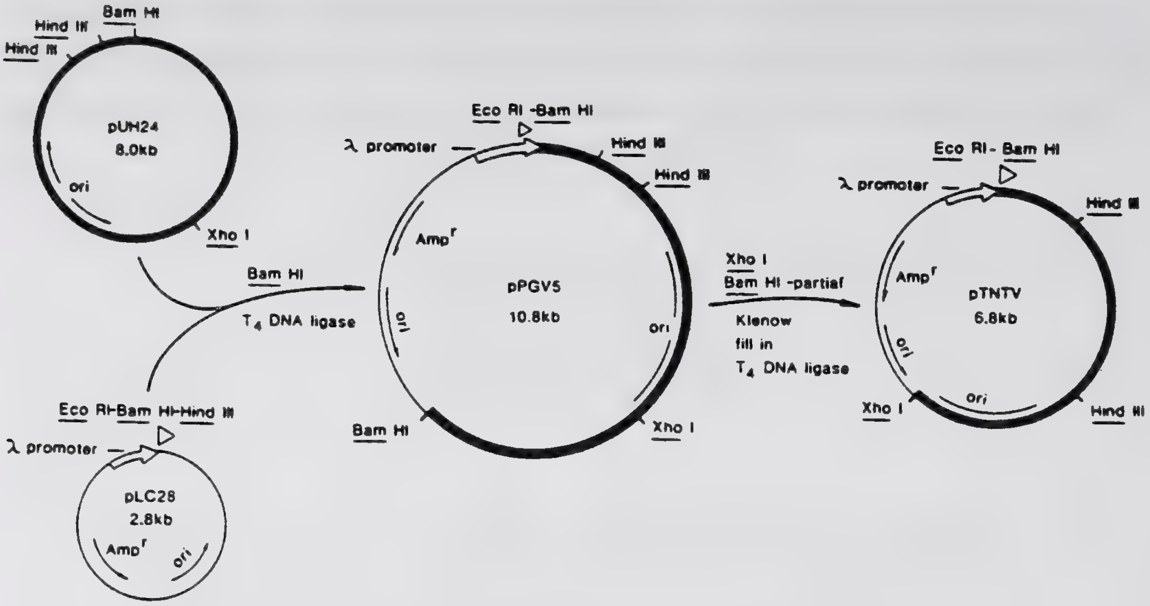

FIGURE 1. Construction of the plasmids pPGV5 and pTNTV.

The two species of cyanobacteria transformed were *A.nidulans* R2 and *A. nidulans* R2SPc. *A. niulans* R2 has been well characterized biochemically and biophysically (Olsen, *et al.,* 1979; Pakrasi, *et al.,* 1985). It contains two plasmids, a 50 kb plasmid known as pUH25, and an 8 kb plasmid known as pUH24 or pANS (van den Hondel, *et al.,* 1971). *A. nidulans* R2SPc is different from *A. nidulans* R2 in that it has been cured of the smaller 8 kb plasmid, pANS (Kuhlemeier, *et al.,* 1981), which helps reduce homologous recombination between genes cloned on the plasmid and a chromosomal gene.

The transformation efficiencies of two different hybrid cloning vectors, pPGV5 and pTNTV were compared. The vector pPGV5 was constructed by digesting both pANS of *A. nidulans* R2 and the *Escherichia coli* plasmid pLC28 with *Bam* HI restriction endonuclease. These two plasmid fragments were then ligated together to form a 10.8 kb hybrid vector (Vann, *et al.,* 1986). This hybrid cloning vector contains the powerful leftward promoter of bacteriophage lambda, allowing for enhanced expression of cloned genes downstream of the promoter (Remant, Stanssens, and Fiers, 1981). It also contains an ampillicin resistance gene and two *Bam* HI restriction endonuclease cloning sites (Figure 1).

The hybird cloning vector pTNTV was modified to make pPGV5 in order to create a smaller vector that contained a unique *Bam* HI restriction site (Figure 1). The *Bam* HI cloning site most distant from the lambda promoter and nonessential cyanobacterial sequences was removed (Nahreini, *et al.,* in press). it was hoped that this vector would transform as efficiently as pPGV5. It is important for a vector to be stable in cells and transform as efficiently as possible so that a higher number of transformants can be obtained for easier manipulation and study. This study was concerned with comparing the tranformation frequency obtained using pTNTV versus pPGV5 in the two cyanobacterial strains.

MATERIALS AND METHODS

Four experiments were performed using the same transformation procedure. First, cell cultures are grown for two days at 30°C on a shaker in BG-11 media

TABLE 1. Transformation frequencies of *Anacystis nidulans* R2 and *A. nidulans* R2SPc. All of the transformation frequencies were calculated in transformants/μg.

Strains	R2	R2SPc	New R2
Experiment 1			
pTNTV	5.6×10^4		
pGV5	1.2×10^2		
Experiment 2			
pTNTV	4.6×10^4	6.6×10^6	
pGV5	4.8×10^4	9.9×10^5	
Experiment 3			
pTNTV	6.2×10^4		
pGV5	6.5×10^4		
Experiment 4			
pTNTV	6.1×10^6		1.5×10^7
pGV5	1.4×10^6		4.6×10^7

(Allen, *et al.*, 1968). Thirty milliliters of these cells were then centrifuged at 5-7 Krpm for ten minutes at 4°C. The pellets were resuspended in 1/2 volume 10 mM NaCl and centrifuged again. The pellets were resuspended again in BG-11 media to a concentration 5×10^8 cells/ml. Fifty nanograms of plasmid DNA was added to 400 μl aliquots of cells. Aliquots of cells containing no added DNA served as controls. All of the cells were covered (to inhibit photosynthesis, which has been found to increase transformation efficiency) and shaken at 30°C overnight.

Dilutions were made and plating was performed on the following day. Aliquots of cells not receiving DNA were diluted to 1×10^{-2}, 10^{-4}, 10^{-5}, and 10^{-6} cells/ml. Cells inoculated with DNA were diluted in the following manner: 1/4x, 1/16x, 1/64x, 1/128x, 1/256x, 1/512x. One hundred microliters of each dilution was plated on BG-11 agar plates. These plates were placed under lights for 4-6 hours to allow time for the antibiotic resistance gene to be expressed. After 4-6 hours, 400 microliters of the selective agent (ampicillin) was added under the agar of the plate, to a final concentration of 0.5 μg/m1. The plates were returned to the light at 30°C for 5-7 days. Colonies were then counted, and the transformation frequencies determined.

The same amount of DNA, 50 ng, was used in transformations by pPGV5 and pTNTV. DNA concentrations of stock solutions were obtained using a UV spectrophotometer set at a wavelength of 260 nm.

RESULTS AND DISCUSSION

The transformation efficiencies obtained in four experiments are illustrated in Table 1. In the first experiment, only *A. nidulans* R2 was transformed. The hybrid cloning vector pPGV5 tranformed this strain at a frequency of 1.2×10^5 transformants/μg, slightly higher than the efficiency of pTNTV which was 5.6×10^4 transformants/μg. This difference was not considered significant, since variations of this magnitude are common.

In the second and third experiments, similiar results were obtained using both plasmid vectors and *A. nidulans* R2 and *A. nidulans* R2SPc. These results suggested that there was no significant difference in the transformation efficiencies, when comparing the two vectors. However, contrary to results obtained in previous studies (Vann, *et al.*, 1986), *A. nidulans* R2SPc transformed at a much higher level than did *A. nidulans* R2, and the latter strain showed much lower transformation efficiency than previously seen.

Prior to performing another experiment, two parameters were altered in order to obtain transformation efficiencies which were similar to those seen in the earlier studies. In the first three experiments, the cyanobacterial cultures had been contaminated with bacterial organisms. It is difficult to maintain axenic cultures of cyanobacteria, and earlier transformation experiments had suggested that slight contamination did not significantly interfere with transformation efficiency (Vann, unpublished observations). However, we decided to perform the transformations with axenic cultures. Previously, cultures had been made axenic by selecting several isolated single colonies from a plate (in order to be sure to select transformable colonies) and growing them up to a dense colony. However, in this case, a recently described technique (Thiel, 1988) was used to make the cultures axenic prior to the fourth experiment. Thiel showed that cyanobacteria (but not bacteria) were protected from arsenate toxicity (10 mM) in the presence high levels of phosphate (100 mM). The cyanobacteria were resistant to this treatment, which killed the contaminating microorganisms.

The last transformations were also performed using a culture called new *A. nidulans* R2, which was kindly donated by Louis Sherman (University of Missouri). The *A. nidulans* R2 used in early experiments had also been obtained from L. Sherman and had previously shown high levels of transformation. It is believed that organic substances which briefly contaminated our water supply during the summer of 1988 may have been responsible for the detrimental effects to the cyanobacteria, resulting in the observed decrease in transformation competency.

The use of the new culture and the removal of contaminants increased transformation efficiencies by two orders of magnitude. Thus, the fourth experiment yielded transformation efficiencies comparable to those seen in other published studies.

Three important conclusions were reached from the data obtained in these experiments. First, both *A. nidulans* R2 and *A. nidulans* R2SPc were transformed by both vectors at a reasonable level as compared to previously reported levels. Second, in the first experiments, contaminating microorganisms reduced transformation efficiencies, but pretreating the cells with 100 mM phosphate and 10 mM arsenate resulted in high efficiencies in experiment four. Third, the transformation efficiencies of pTNTV and pPGV5 are not significantly different in either cyanobacterial species. Thus, pTNTV is capable of high levels of transformation making it a good candidate for gene expression studies.

ACKNOWLEDGMENTS

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PHYSICS AND ASTRONOMY

Chair: David R. Ober
Department of Physics & Astronomy
Ball State University
Muncie, Indiana 47306

Chair-Elect: Uwe Hansen
Department of Physics
Indiana State University
Terre Haute, Indiana 47809

ABSTRACTS

A Liberating Course in Physics. Joseph J. Bellina, Jr., Saint Mary's College, Dept. of Chemistry and Physics, Notre Dame, IN 46556.—A course in physics for non-science students will be described. The course content is limited to a few concepts which are studied in depth to encourage students to rethink their notion of scientific explanations. The rethinking begins early in the course when the stereotypical factual nature of science is symbolically denied by literally denying the motion of the earth, a "fact" which seems beyond denial! What develops is a course in the evolution of ideas about motion in the heavens and on the earth, from pre-Socratic Greeks through the Renaissance to Einstein. The perspective throughout the course is that of paradigm development and change as described by Thomas Kuhn. Weekly laboratory experiments allow the students to investigate the issues discussed in lecture, without the usual cookbook format. The structure of the course and the laboratory exercises will be described.

Measurements of Radon in Muncie City Water. Alice S. Bennett, David Govaer, John Hammer, Natalie Longfellow, and David R. Ober, Ball State University, Muncie, IN 47306.—A Beekman LS 3801 liquid scintillation spectrometer was used to determine radon concentration levels in city drinking water samples taken from several sites in Muncie. Samples were prepared by immediately placing 10 ml of water into a vial containing 10 ml of Mineral Oil Scintillator (85% mineral oil and 15% fluor from NEN Research Products). After three to four hours, water samples and background measurements were conducted in 50-minute intervals. Radon concentrations for several city sites were monitored over a period of weeks. These results will be compared to radon levels obtained for samples taken at the city water plant (before treatment) which were from the White River and city well, the city's sources of drinking water.

Preliminary Network Model of a Silicon Concentrator Solar Cell. Clarence Brooks and Ronald Cosby, Department of Physics and Astronomy, Ball State University, Muncie, IN 47306.—A model for a silicon solar cell under illumination from a line-focusing concentrator has been developed for the simplified case of two or more longitudinal busbars on the surface of the cell. The model consists of a network of one-dimensional $n+ - p - p+$ photodiodes and takes into account bulk and sheet resistances of the cell. A previously developed Fortran program simulates the current-voltage performance of these individual photodiodes under varying levels of illumination. Gauss-Jordan reduction of an augmented matrix (representing Kirchhoff equations) is used to solve for the sheet currents in terms of the photodiode currents. An Ada program has been written to simulate overall current-voltage performance of the cell for any desired number nodes. The cell model characteristics and preliminary simulation results are discussed.

Double Crystal X-Ray Spectrometer for High Sensitivity Lattice Parameter Measurements. ROBERT C. BUSCHERT, MARK A. GUENGERICH, and CARL S. HELRICH, Department of Physics, Goshen College, Goshen, IN 46526.—Single crystal diffraction is not precise enough to measure very small changes in lattice parameter because of wide diffraction peaks (e.g., 0.2°). Double crystal diffractometers with narrow peaks (0.07 to 10 sec. of arc) are necessary for high sensitivity. To solve the problem of indexing or resetting in normal double crystal diffractometers the authors have developed a diffractometer in which the 2nd crystal can be rotated on an axis perpendicular to the planes of diffraction. This facilitates easy alignment and changing of samples and, along with the use of a movable x-ray source, allows the use of only 1 precision axis. The diffractometer can measure change in lattice parameter of $\geqslant 1$ part in 10^7. Results will be presented on some single-crystal semiconductors such as ZnSe and GaAs, including some with thin, single-crystal films.

Assembly and Evaluation of a Radon Calibration Chamber: First Attempt. SHANKAR GURU and JOHN SWEZ, Department of Physics, Indiana State University, Terre Haute, IN 47809.—Attempts to commercially calibrate charcoal cannisters used in randon testing have proven to be very expensive. This paper reports on our progress towards the construction of a radon calibration chamber. Theoretical calculations have been performed utilizing an electronic spreadsheet on the production of radon from the decay of radium (Ra^{226}). Calculations can be extended to sum the total of alpha producing daughters and predict the activity with which a lucas cell would measure in the atmosphere within the chamber. Aqueous solutions traceable to the National Bureau of Standards will be used as the radon generator. The chamber will be attached to a modified lucas cell for continuous alpha monitoring. It is anticipated that the chamber will be utilized during the fall of 1988 in conjunction with a Radon Workshop funded by the Higher Education Commission, State of Indiana. In this workshop, cannisters from facilities who have traceable calibration records will be compared with cannisters calibrated with the ISU generator. One of the beneficial advantages of radon calibrator is the ability to control environmental factors such as temperature, humidity, and air particulate quality.

Low Temperature Physics in the High School Classroom: High Temperature Superconductivity. UWE J. HANSEN, Department of Physics, Indiana State University, Terre Haute, IN 47809.—Title II funds have been obtained from the Indiana State Commission of Higher Education to conduct a series of workshops on high temperature superconductivity with the objective of training high school teachers, as well as providing minimal equipment to introduce this topic into the secondary classroom. In this presentation, we will explore a number of phenomena at liquid Nitrogen temperatures culminating in the demonstration of the floating magnet "Meissner Effect."

Modal Studies of Hand Bells. UWE J. HANSEN, Department of Physics, Indiana State University, Terre Haute, IN 47809 and THOMAS D. ROSSING, Department of Physics, Northern Illinois University, DeKalb, IL 60115.—Hand Bells are traditionally tuned such that the fundamental resonance coincides with the pitch of the bell with the next lowest resonance an octave and a fifth above the fundamental. The air motion inside the mouth gives rise to an additional frequency component at double the fundamental frequency. Higher overtones contribute to the characteristic bell sound. Studying bell modes using near field sound pressure level monitoring, holographic interferometry, and impulse excited modal analysis has permitted an ordering of modes in a pattern not unlike a periodic table. The anomaly in that pattern occurring for a series of low order modes, resulting from the nature of the boundary condition will be discussed.

Air Resistance and Energy Efficient Transportation. MELINDA HARMAN and RUTH HOWES, Department of Physics and Astronomy, Ball State University, Muncie, IN 47306.—Increasing speed reduces the number of miles traveled by an automobile while burning a gallon of gasoline. A major reason for this reduction in efficiency at high speeds is that the force of air resistance on the vehicle increases as the square of velocity. A simple mechanical model for the effect of air resistance on the power consumption of a vehicle has been constructed based on the size and shape of the car. The predictions of the model for several popular automobiles are compared to published data on fuel efficiency. On the basis of this simple model, a lower speed limit on the highway is clearly desirable from the standpoint of energy conservation.

The Effects of Spin-Spin Interaction on the Magnetic Susceptibility of Dilute Magnetic Semiconductors (DMS). CARL S. HELRICH, Goshen College, Department of Physics, Goshen, IN 46526.—In spite of great interest in DMS and their potential technological importance, no general theory exists for the variation of susceptibility with temperature for these materials. Particularly deviations from the Curie-Weiss Law at low temperatures have not been accounted for in a picture based on interactions. Such a theory based on cluster expansions in which exchange effects are added heirarchically is presented. The results, carried to interactions among four spin states, provide good agreement with experiment. The emerging picture also provides an understanding of low temperature deviations from the Curie-Weiss Law in terms of exchange interactions.

Testing Drift Chambers as a Component of Preparation for the Fixed Target Run for Experiment #683 at FNAL. JEFFREY R. JOHANNING, Fermi National Laboratory, Batavia, IL 60510 and GERALD P. THOMAS, Department of Physics and Astronomy, Ball State University, Muncie, IN 47306.—Drift chambers are a major component of tracking devices as used in the large scale electronic detection and measurement systems so often found in high energy physics experiments at major accelerator laboratories such as Fermi National Laboratory. Their optional operation is a highly desirable feature for a successful run of data taking. Such chambers are being tested at FNAL in conjunction with the upcoming run of experiment #683 at FNAL. Details of the design, layout, and procedures used in testing of such DC's will be given. Problems, such as high voltage arcing, will be described and preliminary testing results will be discussed.

X-ray Diffraction Studies of Thin Titanium Nitride Films. DAVID RENNEKE, Department of Physics, Augustana College, Rock Island, IL 61201, JEREMY KROPF, ROBERT BUSCHERT, and CARL HELRICH, Department of Physics, Goshen College, Goshen, IN 46526.—At graze angles (90° - angle of incidence) of ≤ 10 milliradians (mrad) x-ray incident on TiN surfaces are totally reflected from the surface. As the graze angle is increased, penetration can be controlled providing measurement of lattice parameter as a function of depth. Employing a highly collimated $F_eK\alpha$ beam (beam width < 450 μm and graze angle control to within ± 0.1 mrad), we studied total reflection and penetration of x-rays in TiN films sputtered on glass and on Si. We present total reflectivity and penetration curves as well as studies of lattice parameter variation. Under the conditions employed stress/strain relations may be studied in various crystal directions. We present preliminary measurements of the corresponding Young's Moduli.

An Assessment of the Effect of Various Developers on the Sensitivity of Hypersensitized Kodak Technical Pan Film. ROGER L. SCOTT, Department of Physics and Astronomy, Ball State University, Muncie, IN 47306.—The effect of seven common developers was tested on samples of Kodak Technical Pan Film, which were hypersensitized by baking in forming gas, a non-explosive mixture of nitrogen and hyrogen. Before development, the film was exposed on a tube sensitometer, allowing the generation of standard characteristic curves, and thus a determination of relative light sensitivity or "speed."

Implementation and Application of a Single Chip, Off the Shelf, 8-Bit Microcomputer in the Context of Monitoring and Control of a Physical System. GERALD P. THOMAS, Physics Department, Ball State University, Muncie, IN 47306 and ROBERT D. COX, Physics Department, Ball State University, Muncie, IN 47306.—With the advent of single chip microcomputers, the microcomputer control portion of certain physical hardware systems can be less costly as well as occupy less space. Many of these control and monitoring applications require only the limited RAM/ROM featured on such chips. The Motorola MC68705P3 version of an MCU features a bootstrap for loading a user defined monitor yet needs only a few temporary external chips. The monitor then permits desired real-time interaction with peripherals, both with I/O peripherals, for easier RAM access during control/monitor ROM program development, and with the peripherals to be controlled/ monitored themselves. The performance of the chip in the context of a typical application will be discussed.

Design and Implimentation of a Microcomputer-Based Alarm System. SUSAN L. THOMPSON, Physics Department, University of Cincinnati, Cincinnati, Ohio 45221 and GERALD P. THOMAS, Physics Department, Ball State University, Muncie, IN 47306.—A large number of alarm applications for microcomptuers exists, such as detection of burglar movements, and water level movement, etc. Voice message alarms can form an interesting and useful subset of these alarm modes. An alarm system will be presented which consists of a sensing section, a voltage reducer, a debouncer, a KIM system board microcomputer, and a VOTRAX model 200 Personal Speech Synthesis System. The sensing section consists of a light beam and photodetector which outputs a signal that is subsequently reduced and debounced for IRQ vector interrupt service routine that then handshakes voice phoneme data to the VOTRAX via the KIM's data and control ports.. The various components of hardware will be discussed as well as the 6502 assembler program that controls the processing of the alarm interrupt and nature of the voice alert mode. The overall performance of the system will also be discussed.

Analysis of Tracking Error Effects for the Fresnel Mirror Solar Concentrator. YONG ZHAN and RONALD COSBY, Ball State University, Muncie, IN 47306.—A line-focusing Fresnel mirror solar concentrator consists of long mirror segments placed on a base such that incident sunlight is redirected to a desired focal line.

Since sun-tracking is required and economic considerations force the use of simple tracking equipment, proper design requires information on the effects of tracking errors. In this project, optical ray tracing and energy analysis has been used to model this type of concentration under imperfect sun-tracking conditions. Specifically, the model includes mathematical expressions for finding the intensity profiles of concentrated sunlight in planes above the mirror. An Ada computer program has been written to generate intensity profile data for selected ranges of tracking errors and concentrator parameters. Data analysis includes graphical display of profiles, computation of geometrical concentration ratios, and comparisons of the results with the perfect tracking case.

PLANT TAXONOMY

Chair: Paul E. Rothrock
Department of Biology
Taylor University
Upland, Indiana 46989

Chair-Elect: Richard Maxwell
Department of Biology
Indiana University Southeast
4201 Grantline Road
New Albany, Indiana 47150

ABSTRACTS

Fossil Leguminosae from the Eocene of Southeastern North America. Patrick S. Herendeen and David L. Dilcher, Department of Biology, Indiana University, Bloomington, IN 47405.——Fossil Leguminosae are among the most abundant and diverse elements in the Eocene Claiborne Formation of southeastern North America. The three legume subfamilies (Caesalpinioideae, Mimosoideae, Papilionoideae) are represented by numerous leaflet and fruit types and by several types of flowers and inflorescences. At present, 22 types of fossil leaflets and 18 types of fossil pods are recognized from 10 localities. There are often numerous extant legume genera that are generally comparable to a particular fossil leaflet or pod. Details of venation and cuticle are used to further evaluate these similarities. Examples of fossils representing the tribes Caesalpinieae, Detarieae, Mimoseae, Sophoreae, Dalbergieae, and Millettieae will be presented. In some cases, it has been possible to determine which types of fossil leaflets and pods may have been produced by the same plant species. These fossils are important in that they document both the early diversity of the Leguminosae and the phytogeographical affinities of the Eocene flora in southeastern North America.

Clarification of the Identity and Taxonomy of *Carex albolutescens* Schw. and *C. longii* Mack. (Cyperaceae). Paul E. Rothrock, Department of Biology, Taylor University, Upland, IN 46989.——Some current regional floras from eastern North America consider *Carex longii* Mack. to be synonymous with *Carex albolutescens* Schw. An examination of type specimens, herbarium material from various parts of the range, and several population samples showed that there are two morphologically distinct taxa. They differ in spikelet shape, pistillate scale apex, and perigynial beak shape. These differences are especially sharp for populations from the eastern seaboard region. Microscopic study of culm cross-sections also revealed significant differences in wall thickness, the amount of sclerenchyma tissue, and size of epidermal cells. In at least one regional flora, the *Vascular Flora of the Carolinas,* the reduction of *Carex longii* to synonomy was based in part upon a misapplication of the name *C. festucacea.*

A Field Guide to Indiana Wildflowers. Kay Yatskievych, 4118 Utah St., St. Louis, Missouri 63116.——*A Field Guide to Indiana Wildflowers* will enable persons with little or no botanical training to quickly and reliably identify all 1650 species of Indiana plants (excluding grasses, sedges, rushes, and trees) using a combination of photographs, drawings, and text. The introductory section “What Is a Flower?” defines and illustrates pistillate, staminate, and perfect flowers, inflorescences, and specialized flowers. Based on information from this section, “The Family Finder” then uses a simplified method of looking at flowers and counting their parts and uses drawings to locate the family. Family names are those used in Cronquist (1981) and photographs (ca. 650, which roughly equal the number of genera) will facilitate recognition of major visual groups within each family. Visually similar species have brief text and usually line drawings of details necessary to distinguish them from the one photographed. This simple, visual, and scientifically accurate presentation will be useful to amateurs, interpretive naturalists, students, teachers, botanists, and scientists in related disciplines. Indiana University Press has expressed interest in publishing this book, which will be completed within the next year.

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VASCULAR PLANTS OF HOOSIER PRAIRIE NATURE PRESERVE, LAKE COUNTY, INDIANA

John A. Bacone and Thomas W. Post
Indiana Department of Natural Resources
Indianapolis, Indiana 46204
and
Kenneth Klick
Indiana Dunes National Lakeshore
Porter, Indiana 46304

INTRODUCTION

Hoosier Prairie Nature Preserve is located in Lake County, Indiana (Sec. 33 and 34, T36N, R9W; Sec. 3 and 4, T35N, R9W; Highland 7.5′ topographic quadrangle). The original 304-acre tract was purchased by the State of Indiana in 1976, and subsequently an additional 31 acres were transferred to the State by the National Park Service. The tract, which is now part of the Indiana Dunes National Lakeshore, is a dedicated State nature preserve and national natural landmark. It is owned and managed by the Division of Nature Preserves, Indiana Department of Natural Resources. Hoosier Prairie is located in the Chicago Lake Plain Section of the Northwestern Morainal Natural Region (Homoya, *et al.*, 1985). It contains several natural communities and provides habitat for a number of rare vascular plants.

The soil types are primarily sandy soils on the higher ground (Brems fine sand and Plainfield fine sand), Watseka and Maumee loamy sands at intermediate topographic levels, and Gilford mucky sandy loam in the swales (Persinger, 1972). The topography is gently rolling and varies from 618′ in the swales to 625′ on the rises.

METHODS

Hoosier Prairie has been studied by a number of botanists, since its "discovery" as one of Indiana's remaining prairie remnants in the 1960's. These botanists compiled a master plant species list, which was periodically updated. Following the area's acquisition as a nature preserve, permanent plots and belt transects were installed and periodically sampled for species' presence. This information, in addition to continual botanizing, has resulted in the list presented in this paper.

NATURAL COMMUNITIES

Several natural communities (Homoya, *et al.*, 1985) were delineated, and their plants identified. The natural communities were delineated based on dominant vegetation, topographic position, and soil type. These communities grade into one another and in some cases, occupy a very narrow width, largely in response to the gentle change in topography. For purposes of this paper, the following communities are identified, and their major components are listed below.

Sand savanna. The dominant tree here is *Quercus velutina*, followed by *Quercus alba*. Characteristic understory species include *Andropogon scoparius*, *Koeleria cristata*, *Comptonia peregrina*, *Liatris aspera*, *Pteridium aquilinum latiusculum*, and *Carex pennsylvanica*. This community type occurs on the higher, drier, sandy soils.

Mesic sand prairie. This community type includes dry-mesic sand prairie and wet-mesic sand prairie, which are sometimes treated separately. It occupies slopes and level soils below the savannas and above the swales. Characteristic species includes *Andropogon gerardi*, *Helianthus mollis*, *Parthenium integrifolium*, *Euphorbia corollata*, *Sorghastrum nutans*, and *Liatris spicata*.

Wet prairie/sedge meadow. These communities are sometimes distinct and sometimes blend into one another. They occupy the loamy sand soils on the lower topographic levels just above the marches. Characteristic species include a variety of sedges, primarily *Carex spp.*, *Calamagrostis canadensis*, *Panicum virgatum*, *Spartina pectinata*, *Eryngium yuccifolium*, *Lilium michiganense*, and *Dryopteris thelypteris pubescens*.

Marsh. Marches occur in the lower "swales" on mucky soils. They are primarily dominated by cattails (*Typha latifolia* and *T. angustifolia*), bullrushes (*Scirpus validus creber*), and numerous other species, including *Eupatorium perfoliatum*, *Galium asprellum*, *Lysimachia terrestris*, and *Scirpus acutus*.

Disturbed ground. A portion of the Hoosier Prairie Nature Preserve has been disturbed in the past, primarily by agriculture. While primarily confined to the 31-acre tract located at the southeast corner of Main Street and Kennedy Avenue, disturbed areas are also found along roads, pipelines, and powerline corridors. These areas harbor many non-native species as well as many of the native species found in the open prairie/wetland communities.

Shaded habitats. These areas consist primarily of aspen (*Populus tremuloides*) thickets, overgrown black oak savannas, and willow (*Salix spp.*) thickets. They are in a continual state of change, determined by the frequency and intensity of fires. The shaded habitats contain species such as *Osmorhiza claytonii*, *Botrychium virginianum*, *Claytonia virginica*, and *Podophyllum peltatum*.

PLANT SPECIES

The list of vascular plants presently known from Hoosier Prairie Nature Preserve (Table 1) is annotated to show the primary natural communities in which the species are found. These determinations are based primarily on sampling data, which are on file in the Division of Nature Preserves' office, and on field observations. The list is further annotated to show which species are non-native and which are considered rare in Indiana (Aldrich, *et al.*, 1986; Bacone and Hedge, 1980). The nomenclature is according to Swink and Wilhelm (1979).

Five hundred sixty species, representing 274 genera, were identified on this preserve. Of these, 92 are non-native taxa. Thirty-one taxa are considered endangered, threatened or rare, or are on the "watch" list in Indiana (Aldrich, *et al.*, 1986; Bacone and Hedge, 1980). Twelve taxa are considered endangered, including *Corydalis sempervirens*, *Geranium bicknellii*, *Malaxis unifolia*, *Polytaenia nuttallii*, and *Utricularia subulata*. The six taxa considered threatened include *Aster ptarmicoides*, *Carex trichocarpa*, and *Eriophorium angustifolium*. Examples of the nine species considered rare include *Comptonia peregrina* and *Pogonia ophioglossoides*. Four species are on the "watch list," including *Monotropa hypopithys*.

ACKNOWLEDGMENTS

The authors would like to thank Robert Betz, Floyd Swink, Ray Schulenberg, Gerould Wilhelm, and many of the other botanists, who provided the original plant lists for the prairie. We are extremely grateful to Irene Herlocker-Meyer without whose efforts this prairie would never have been preserved. Our special thanks go to Michelle Martin of the Division of Nature Preserves for providing so much help with the preparation of the computerized species lists used in Table 1 and to Ron Hellmich for proofreading assistance.

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TABLE 1. Vascular plants of the Hoosier Prairie Nature Preserve (e = endangered, t = threatened, r = rare, w = watch list, a = alien. mar = marsh, sm/wp = sedge meadow/wet prairie, mp = mesic prairie, sav = savanna, dist = disturbed, and shad = shaded).

Species Name	**Natural Community**					
	mar	**sm/wp**	**mp**	**sav**	**dist**	**shad**
Acalypha rhomboidea		x			x	
Acer saccharinum						x
^{a} *Achillea millefolium*			x	x	x	
Agrimonia parviflora		x				
Agrimonia pubescens					x	
^{a} *Agropyron repens*					x	
^{a} *Agrostis alba*			x	x	x	
Agrostis hyemalis				x		
Aletris farinosa			x			
Alisma subcordatum	x					
Alisma triviale	x					
Allium canadense			x			
^{a} *Allium vineale*					x	
Alopecurus aequalis	x					
^{a} *Alopecurus carolinianus*	x					
^{a} *Amaranthus retroflexus*					x	
Ambrosia artemisiifolia v. *elatior*			x		x	
Ambrosia trifida					x	

Species Name	**Natural Community**					
	mar	**sm/wp**	**mp**	**sav**	**dist**	**shad**
Amelanchier laevis						x
Amorpha canescens				x		
Amphicarpa bracteata				x	x	
Andropogon gerardi		x	x	x		
Andropogon scoparius			x	x		
Anemone cylindrica				x		
Anemone quinquefolia v. *interior*			x	x		
Anemonella thalictroides						x
Antennaria neglecta			x			
Antennaria plantaginifolia			x			
Apios americana			x	x	x	
Apocynum androsaemifolium			x	x		
Apocynum cannabinum		x		x		
Apocynum sibiricum			x	x		
Arabis lyrata				x		
Aralia nudicaulis				x		
Arenaria lateriflora		x	x	x		
Artemisia caudata				x		
Asclepias amplexicaulis			x			
Asclepias hirtella			x			
Asclepias incarnata		x				
Asclepias syriaca					x	
Ascelepias tuberosa				x		
Asclepias verticillata			x		x	
[a] *Asparagus officinalis*				x	x	
Aster azureus		x	x	x		
Aster dumosus		x	x	x		
Aster ericoides			x	x		
Aster laevis				x		
Aster lateriflorus		x		x		
Aster linariifolius			x	x		
Aster novae-angliae		x	x			
Aster pilosus				x		
Aster praealtus				x		
[t] *Aster ptarmicoides*			x			
Aster simplex		x	x	x		
Aster umbellatus		x	x	x		
Athyrium filix-femina v. *michauxii*						x
Baptisia leucantha		x	x	x		
[a] *Barbarea vulgaris*					x	
Bartonia virginica			x	x		
[a] *Berberis thunbergii*					x	
Bidens comosa					x	
Bidens coronata	x	x				
Bidens frondosa	x	x				

Species Name	**Natural Community**					
	mar	**sm/wp**	**mp**	**sav**	**dist**	**shad**
Blephilia hirsuta						x
Boehmeria cylindrica v. *drummondiana*						x
Boltonia latisquama v. *recognita*	x					
Botrychium virginianum						x
[a] *Bromus inermis*					x	
Bromus purgans						x
[a] *Bromus tectorum*					x	
Bulbostylis capillaris					x	
Cacalia tuberosa		x				
Calamagrostis canadensis	x	x	x	x		
Calamagrostis inexpansa v. *brevior*			x			
Callitriche heterophylla	x					
Calopogon pulchellus		x				
Caltha palustris	x					
Campanula aparinoides		x	x			
[a] *Capsella bursa-pastoris*					x	
Cardamine bulbosa	x					
Cardamine parviflora v. *arenicola*					x	
Cardamine pensylvanica					x	
Carex artitecta x *pensylvanica*				x		
Carex bicknellii			x			
Carex buxbaumii		x				
Carex cephalophora						x
[e] *Carex conoidea*			x			
[t] *Carex eburnea*			x			
Carex emmonsii				x		
Carex foenea			x			
Carex gracillima				x		
Carex haydenii		x				
Carex hystricina		x				
Carex lanuginosa	*x*					
Carex lasiocarpa v. *americana*	*x*					
Carex meadii		x				
Carex pensylvanica			x	x		
Carex rostrata v. *utriculata*	x					
Carex sartwellii	x	x				
Carex scoparia	x					
Carex sterilis		x				
Carex stricta		x				

Species Name	Natural Community					
	mar	sm/wp	mp	sav	dist	shad
Carex suberecta		x				
Carex tetanica		x				
Carex tribuloides		x				
[t] *Carex trichocarpa*	x					
Carex vulpinoidea		x				
Castilleja coccinea			x			
Ceanothus americanus				x		
[a] *Centurium pulchellum*					x	
Cephalanthus occidentalis	x					
[a] *Cerastium brachypodum*					x	
[a] *Cerastium vulgatum*					x	
[a] *Chenopodium album*					x	
[a] *Chrysanthemum leucanthemum* v. *pinnatifidum*					x	
[a] *Cichorium intybus*					x	
Cicuta maculata	x	x				
[a] *Cirsium arvense*			x	x	x	
Cirsium discolor			x	x		
Cirsium muticum		x	x	x		x
[a] *Cirsium vulgare*					x	
Claytonia virginica						x
Comandra richardsiana		x	x	x		
[r] *Comptonia peregrina*			x	x		
Convolvulus sepium		x	x	x		
Corallorhiza odontorhiza						x
Coreopsis lanceolata			x			
Coreopsis palmata			x	x		
Coreopsis tripteris		x	x	x		
Cornus obliqua		x				
Cornus racemosa				x	x	
Cornus stolonifera						x
Corydalis sempervirens				x		
Corylus americana				x		x
[a] *Crotalaria sagittalis*					x	
Cuscuta sp.			x	x		
[e] *Cyperus dentatus*		x				
Cyperus ferruginescens		x				
Cyperus rivularis		x				
Cyperus strigosus	x					
[w] *Cypripedium calceolus* v. *pubescens*				x		
[r] *Cypripedium candidum*			x			
[a] *Dactylis glomerata*					x	
[a] *Daucus carota*				x	x	
Desmodium canadense			x	x		
Desmodium ciliare			x			
Desmodium glutinosum			x	x		

Species Name	**Natural Community**					
	mar	**sm/wp**	**mp**	**sav**	**dist**	**shad**
Desmodium illinoense			x			
Desmodium nudiflorum				x		
Desmodium paniculatum				x		
[a] *Dianthus armeria*					x	
[r] *Diervilla lonicera*				x		
Dodecatheon meadia			x			
[r] *Drosera intermedia*			x			
Dryopteris thelypteris v. *pubescens*		x	x			
Dulichium arundinaceum	x					
Echinochloa crusgalli					x	
Eleocharis acicularis	x					
Eleocharis compressa		x		x		
Eleocharis elliptica		x				
Eleocharis obtusa		x				
Eleocharis palustris v. *major*	x	x				
[r] *Eleocharis pauciflora* v. *fernaldii*		x				
Eleocharis smallii		x				
[e] *Eleocharis wolfii*		x	x			
Elymus virginicus						x
Epilobium angustifolium		x				
Epilobium coloratum		x	x			
Epilobium glandulosum v. *adenocaulon*		x				
Epilobium leptophyllum	x			x		
Epilobium strictum		x				
Equisetum arvense			x	x		
Equisetum hyemale			x			
Erechtites hieracifolia	x	x	x	x		
Erigeron canadensis					x	
Erigeron philadelphicus	x					
Erigeron pulchellus			x			
Erigeron strigosus			x			
[t] *Eriophorum angustifolium*		x				
Eryngium yuccifolium		x	x	x		
Eupatorium altissimum			x			
Eupatorium maculatum	x					
Eupatorium perfoliatum	x	x				
Eupatorium serotinum					x	
Euphorbia corollata		x	x	x		
[a] *Euphorbia maculata*					x	
[a] *Euphorbia supina*					x	
Fimbristylis autumnalis v. *mucronulata*		x				

Species Name	**Natural Community**					
	mar	**sm/wp**	**mp**	**sav**	**dist**	**shad**
Fragaria virginiana		x	x	x		
Fraxinus pennsylvanica v. *subintegerrima*						x
Galium aparine				x	x	
Galium asprellum	x	x				
Galium boreale			x	x		
Galium concinnum				x		
Galium obtusum	x	x	x	x		
Galium tinctorium	x	x				
Galium trifidum		x				
Gaylussacia baccata			x	x		
Gentiana crinita	x					
[t] *Gentiana puberula*			x			
Gentiana saponaria			x	x		
[e] *Geranium bicknellii*				x		
Gerardia flava				x		
Gerardia paupercula		x				
Gerardia purpurea		x	x	x		
[e] *Gerardia skinneriana*			x			
Gerardia tenuifolia			x			
Geum laciniatum v. *trichocarpum*		x			x	
Glyceria septentrionalis	x					
Gnaphalium obtusifolium		x				
Gratiola neglecta					x	
[r] *Habenaria flava* v. *herbiola*		x	x			
[w] *Habenaria lacera*		x				
Helenium autumnale		x				
[a] *Helenium nudiflorum*		x				
Helianthemum bicknellii					x	
Helianthemum canadense				x	x	
Helianthus divaricatus				x	x	
Helianthus grosseserratus		x	x			
Helianthus laetiflorus v. *rigidus*			x	x		
Helianthus mollis		x	x	x		
Helianthus occidentalis			x			
[a] *Helianthus petiolaris*					x	
[a] *Hemerocallis fulva*					x	
Heracleum maximum					x	
Heuchera richardsonii			x	x		
Hieracium canadense v. *fasciculatum*				x		
Hierochloe odorata			*x*			
[a] *Hordeum jubatum*					x	
Houstonia caerulea		x	x	x		
Hydrophyllum virginianum						x

Species Name	Natural Community					
	mar	sm/wp	mp	sav	dist	shad
Hypericum canadense		x	x			
Hypericum gentianoides					x	
Hypericum mutilum		x	x			
[a] *Hypericum perforatum*					x	
Hypericum virginicum v. *fraseri*	x	x				
Hypoxis hirsuta				x		
Impatiens capensis				x		
[a] *Ipomoea hederacea*					x	
[a] *Iris germanica*					x	
Iris virginica v. *shrevei*	x	x				
Juglans nigra						x
Juncus acuminatus		x				
Juncus alpinus v. *rariflorus*		x				
Juncus biflorus	x					
Juncus brachycarpus		x				
Juncus bufonius		x				
Juncus canadensis		x				
Juncus dudleyi		x				
Juncus effusus v. *solutus*		x	x			
Juncus greenei		x				
Juncus interior		x				
Juncus marginatus		x				
Juncus tenuis					x	
Juncus torreyi		x				
Koeleria cristata				x		
Krigia biflora			x	x		
Lactuca canadensis				x		
Lathyrus palustris		x				
Lechea leggettii v. *moniliformis*				x		
Lechea villosa			x			
Leersia oryzoides		x				
Lemna minor		x				
[a] *Lepidium campestre*					x	
Lepidium virginicum					x	
Lespedeza capitata			x	x		
Lespedeza hirta				x		
Liatris aspera			x	x		
Liatris cylindracea			x			
Liatris spicata		x	x	x		
Lilium michiganense		x				
Lilium philadelphicum v. *andinum*			x			
[a] *Linaria vulgaris*					x	

Species Name	**Natural Community**					
	mar	**sm/wp**	**mp**	**sav**	**dist**	**shad**
Lindernia anagallidea		x				
Lindernia dubia					x	
Linum medium v. *texanum*		x				
[a] *Linum usitatissimum*					x	
Liparis lilifolia			x		x	
[w] *Liparis loeselii*			x			
Lithospermum canescens			x			
Lithospermum croceum				x		
Lobelia cardinalis			x			
Lobelia spicata			x			
[a] *Lonicera tatarica*					x	x
Ludwigia alternifolia		x	x			
Ludwigia palustris v. *americana*	x	x				
Ludwigia polycarpa	x					
Lupinus perennis v. *occidentalis*			x	x		
[e] *Luzula acuminata*						x
Luzula multiflora		x				
[a] *Lychnis dioica*					x	
[e] *Lycopodium inundatum*		x				
Lycopus americanus		x	x	x		
Lycopus rubellus		x				
Lycopus uniflorus	x	x	x	x		
Lycopus virginicus	x					
Lysimachia lanceolata		x		x		
Lysimachia quadriflora		x				
Lysimachia terrestris	x	x				
Lysimachia thyrsiflora	x					
Lythrum alatum	x	x	x			
[a] *Lythrum salicaria*	x					
Maianthemum canadense			x	x		
[e] *Malaxis unifolia*						x
[a] *Medicago lupulina*					x	
[a] *Melilotus alba*				x	x	
[a] *Melilotus officinalis*					x	
Mentha arvensis v. *villosa*		x				
Mimulus ringens	x					
[a] *Mirabilis nyctaginea*					x	
[a] *Mollugo verticillata*					x	
Monarda fistulosa			x	x		
[w] *Monotropa hypopithys*				x		
Muhlenbergia glomerata	x					
Muhlenbergia mexicana		x	x	x		
Muhlenbergia schreberi					x	
Myosotis verna					x	

Species Name	**Natural Community**					
	mar	**sm/wp**	**mp**	**sav**	**dist**	**shad**
Najas flexilis	x					
Nyssa sylvatica						x
Oenothera biennis			x	x		
Oenothera pilosella			x			
Onoclea sensibilis		x	x	x		
Ophioglossum vulgatum v. *pseudopodum*		x				
[a] *Ornithogalum umbellatum*					x	x
Osmorhiza claytoni						x
Osmunda cinnamomea			x	x		
Osmunda claytoniana				x		x
Osmunda regalis v. *spectabilis*		x	x			
Oxalis europaea					x	
Oxalis stricta					x	
Oxalis violacea				x		
Oxypolis rigidior		x				
Panicum agrostoides		x				
Panicum depauperatum				x		
Panicum implicatum		x		x		
Panicum meridionale					x	
Panicum oligosanthes v. *scribnerianum*				x	x	
Panicum sphaerocarpon			x			
Panicum spretum					x	
Panicum villosissimum			x			
Panicum virgatum		x	x	x		
Parthenium integrifolium			x	x		
Parthenocissus inserta				x		
[a] *Pastinaca sativa*					x	
Pedicularis canadensis			x	x		
Pedicularis lanceolata			x			
Penstemon calycosus						x
Penstemon digitalis						x
Penthorum sedoides	x					
Petalostemum purpureum			x			
[a] *Phleum pratense*					x	
Phlox glaberrima v. *interior*		x	x	x		
[a] *Phlox paniculata*					x	
Phlox pilosa				x		
Physalis heterophylla					x	
Physalis subglabrata				x		
Physostegia virginiana			x			
[a] *Plantago lanceolata*					x	
[a] *Plantago major*					x	
Plantago rugelii					x	

Species Name	**Natural Community**					
	mar	**sm/wp**	**mp**	**sav**	**dist**	**shad**
[a] *Plantago major*					x	
Plantago rugelii					x	
[a] *Plantago virginica*					x	
[a] *Poa annua*				x		
[a] *Poa compressa*				x		
[a] *Poa pratensis*			x	x	x	
Podophyllum peltatum						x
[r] *Pogonia ophioglossoides*		x				
Polygala cruciata v. *aquilonia*		x				
Polygala polygama v. *obtusata*				x		
Polygala sanguinea			x			
Polygala senega			x			
Polygala verticillata v. *isocycla*			x	x		
Polygonatum canaliculatum						x
Polygonum amphibium v. *stipulaceum*	x	x				
[e] *Polygonum careyi*	x					
Polygonum coccineum	x	x	x			
Polygonum hydropiper	x					
Polygonum hydropiperoides		x				
Polygonum pensylvanicum v. *laevigatum*		x				
[a] *Polygonum persicaria*					x	
Polygonum punctatum					x	
Polygonum scandens		x				
Polygonum tenue					x	
[e] *Polytaenia nuttallii*			x			
Populus deltoides		x	x			
Populus grandidentata					x	
Populus tremuloides		x	x	x	x	x
[a] *Portulaca oleracea*					x	
Potentilla arguta			x			
Potentilla norvegica			x			
[a] *Potentilla recta*					x	
Potentilla simplex		x	x	x		
Prenanthes alba						x
[r] *Prenanthes aspera*			x			
Prenanthes racemosa				x		
Proserpinaca palustris v. *crebra*	x	x				
Prunella vulgaris v. *lanceolata*			x		x	
Prunus pumila			x			
Prunus serotina			x	x		

Species Name	**Natural Community**					
	mar	**sm/wp**	**mp**	**sav**	**dist**	**shad**
Prunus virginiana						x
Ptelea trifoliata						x
Pteridium aquilinum v. *latiusculum*			x	x		
Pycnanthemum tenuifolium			x			
Pycnanthemum virginianum		x	x	x		
[a] *Pyrus malus*					x	
Pyrus melanocarpa			x	x		
Quercus alba				x		
Quercus velutina				x		
Ranunculus abortivus						x
Ranunculus fascicularis					x	
Ranunculus flabellaris		x				
Ranunculus pensylvanicus	x					
Ratibida pinnata			x			
[a] *Rhamnus cathartica*			x	x		x
[a] *Rhamnus frangula*			x	x	x	x
Rhexia virginica		x				
Rhus copallina v. *latifolia*		x	x	x		
Rhus glabra		x	x	x		
Rhus radicans				x		x
Rhus typhina				x		
Rhynchospora capitellata	x					
[e] *Rhynchospora globularis* v. *recognita*		x				
Ribes missouriense						x
[a] *Robinia pseudo-acacia*					x	
Rorippa islandica v. *fernaldiana*	x					
Rosa carolina		x		x		
[a] *Rosa multiflora*					x	
[a] *Rosa palustris*		x				
Rubus allegheniensis		x	x	x	x	
Rubus flagellaris		x	x	x		x
Rubus hispidus v. *obovalis*		x	x	x		
Rubus occidentalis					x	x
Rudbeckia hirta			x	x		
[a] *Rumex acetosella*					x	
[a] *Rumex crispus*					x	
Rumex verticillatus	x					
Sagittaria brevirostra	x					
Sagittaria latifolia	x	x				
Salix amygdaloides		x	x			
[a] *Salix babylonica*					x	
Salix discolor		x				

Species Name	**Natural Community**					
	mar	**sm/wp**	**mp**	**sav**	**dist**	**shad**
Salix glaucophylloides v. *glaucophylla*		x	x	x		
Salix humilis		x	x	x		
Salix interior		x				
Salix nigra	x					
Sambucus canadensis						x
Sanicula gregaria					x	
Sanicula marilandica			x			
[a] *Saponaria officinalis*					x	
Sassafras albidum						x
[e] *Satureja arkansana*			x			
Saxifraga pensylvanica			x			
Scirpus acutus	x					
Scirpus americanus	x					
Scirpus atrovirens	x					
Scirpus cyperinus		x				
Scirpus lineatus		x				
Scirpus validus v. *creber*	x					
Scleria triglomerata			x			
Scrophularia lanceolata				x		
Scutellaria epilobiifolia	x	x		x		
Scutellaria lateriflora		x				
Senecio pauperculus v. *balsamitae*		x	x			
Senecio plattensis			x			
Silene antirrhina				x		
Silene stellata				x	x	
Silphium integrifolium		x	x			
Silphium laciniatum			x			
Silphium terebinthinaceum			x			
Sisyrinchium albidum			x			
Sisyrinchium angustifolium			x			
Sium suave	x	x				
Smilacina racemosa		x	x	x	x	
Smilacina stellata				x		
[a] *Solanum carolinense*					x	
[a] *Solanum dulcamara*					x	
Solidago altissima		x	x	x	x	x
Solidago gigantea		x	x			
Solidago graminifolia v. *media*		x	x	x		
Solidago graminifolia v. *nuttallii*		x	x	x		
Solidago gymnospermoides		x	x			
Solidago juncea		x	x	x		
Solidago missouriensis v. *fasciculata*			x			

Species Name	**Natural Community**					
	mar	**sm/wp**	**mp**	**sav**	**dist**	**shad**
Solidago nemoralis		x				
Solidago ohioensis		x	x			
Solidago riddellii		x				
Solidago rigida			x			
Solidago rugosa		x		x		
Solidago speciosa				x		
Solidago tenuifolia				x		
Solidago uliginosa		x				
[a] *Sonchus uliginosus*				x		
Sorghastrum nutans		x	x	x		
Spartina pectinata	x	x	x			
Sphenopholis intermedia		x				
Spiraea alba		x	x			
Spiraea tomentosa v. *rosea*		x				
Spiranthes cernua		x				
Sporobolus heterolephis			x			
Stachys palustris v. *homotricha*		x	x			
Stachys tenuifolia v. *hispida*						x
[a] *Stellaria graminea*					x	
Stipa spartea				x		
[t] *Strophostyles leiosperma*					x	
[a] *Syringa vulgaris*					x	
Taenidia integerrima			x			
[a] *Taraxacum officinale*					x	
Tephrosia virginiana				x		
Teucrium canadense		x				
Thalictrum dasycarpum			x	x		
Thalictrum dioicum			x			
Thalictrum revolutum		x	x	x		
Tradescantia ohiensis			x	x		
[a] *Tragopogon pratensis*					x	
[a] *Trifolium agrarium*					x	
[a] *Trifolium hybridum*					x	
[a] *Trifolium pratense*					x	
[a] *Trifolium repens*					x	
Trillium recurvatum						x
Typha angustifolia	x					
Typha latifolia	x					
Ulmus americana						x
Ulmus rubra						x
Urtica procera		x	x			
[e] *Utricularia subulata*		x				
Utricularia vulgaris	x					
Vaccinium angustifolium v. *laevifolium*			x	x		

Species Name	**Natural Community**					
	mar	**sm/wp**	**mp**	**sav**	**dist**	**shad**
[a] *Verbascum thapsus*					x	
Verbena hastata		x	x			
Verbena stricta					x	
Verbena urticifolia						x
Vernonia fasciculata		x				
Vernonia missurica					x	
[a] *Veronica arvensis*					x	
Veronica peregrina					x	
Veronica scutellata	x					
[a] *Veronica serpyllifolia*					x	
Veronicastrum virginicum		x	x			
Viburnum lentago						x
Vicia americana					x	
Viola candensis						x
Viola fimbriatula				x		
Viola lanceolata		x	x	x		
Viola papilionacea		x				
Viola pedata v. *lineariloba*			x			
Viola sagittata			x	x		
Viola sororia					x	
Vitis riparia		x		x	x	
[a] *Xanthium strumarium*					x	
Xyris torta		x	x			
Zizia aurea		x	x			

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THE DISTRIBUTION AND STATUS OF BOG BLUEGRASS (*POA PALUDIGENA*) IN INDIANA

Michael A. Homoya
Indiana Division of Nature Preserves
Indiana Department of Natural Resources
Indianapolis, Indiana 46204

INTRODUCTION

Bog bluegrass (*Poa paludigena* Fern. & Wieg.) is a little known and presumed rare grass of the cool temperate regions of eastern North America. Although there were several collections of the grass in the early 1900's from many States ranging from Wisconsin to New York, today very few extant populations are known. Because of concern among conservation biologists regarding the global status of bog bluegrass, a status survey grant program was initiated by the U.S. Fish and Wildlife Service (USFWS). The Division of Nature Preserves, Indiana Department of Natural Resources (IDNR), received a grant in 1988 to determine the status of bog bluegrass in Indiana. The results of that survey are reported herein.

METHODS

Initially, historical collecting sites of bog bluegrass were visited to determine current population status. The location of new sites with potential bog bluegrass habitat was determined by checking soil surveys, aerial photographs, and the Indiana Natural Heritage Program (INHP) database located at the IDNR in Indianapolis. Sites were visited during the peak of anthesis and seed-formation (from mid-May through the end of June). In most cases, vouchers were taken and deposited in the Deam Herbarium at Indiana University (IND).

DISTRIBUTION

In Indiana, bog bluegrass is confined primarily to the northern half of the State, in areas defined by Homoya, *et al.* (1985) as the Northern Lakes, Central Till Plain, and Northwestern Morainal natural regions. There are some exceptions to the northern distribution, with populations occurring in Dubois, Jackson, Fayette, and Owen Counties. Figure 1 shows the county distribution of bog bluegrass in Indiana. All of the populations, with one exception, occur in formerly glaciated areas, most within the zone of Wisconsinan glaciation. The southern Indiana populations occur in an area of pre-Wisconsinan glaciation. The one exception, in Dubois County, is extremely close to the glacial border.

Occurrence of bog bluegrass in any given locality is dependent upon the presence of appropriate habitat. In all cases, that habitat consists of a highly organic substrate (e.g., muck) saturated by constant ground water seepage. Habitats with these conditions are commonly called seep springs, seepage swamps, or fens. Prime conditions exist in a seep community where a sparse canopy exists, such as formed by tamarack (*Larix laricina* (DuRoi) K. Koch), black ash (*Fraxinus nigra* Marsh), alder (*Alnus serrulata* (Ait.) Willd. and *A. rugosa* (DuRoi) Spreng.), yellow birch (*Betula lutea* Michx. f.), or poison sumac (*Rhus vernix* L.).

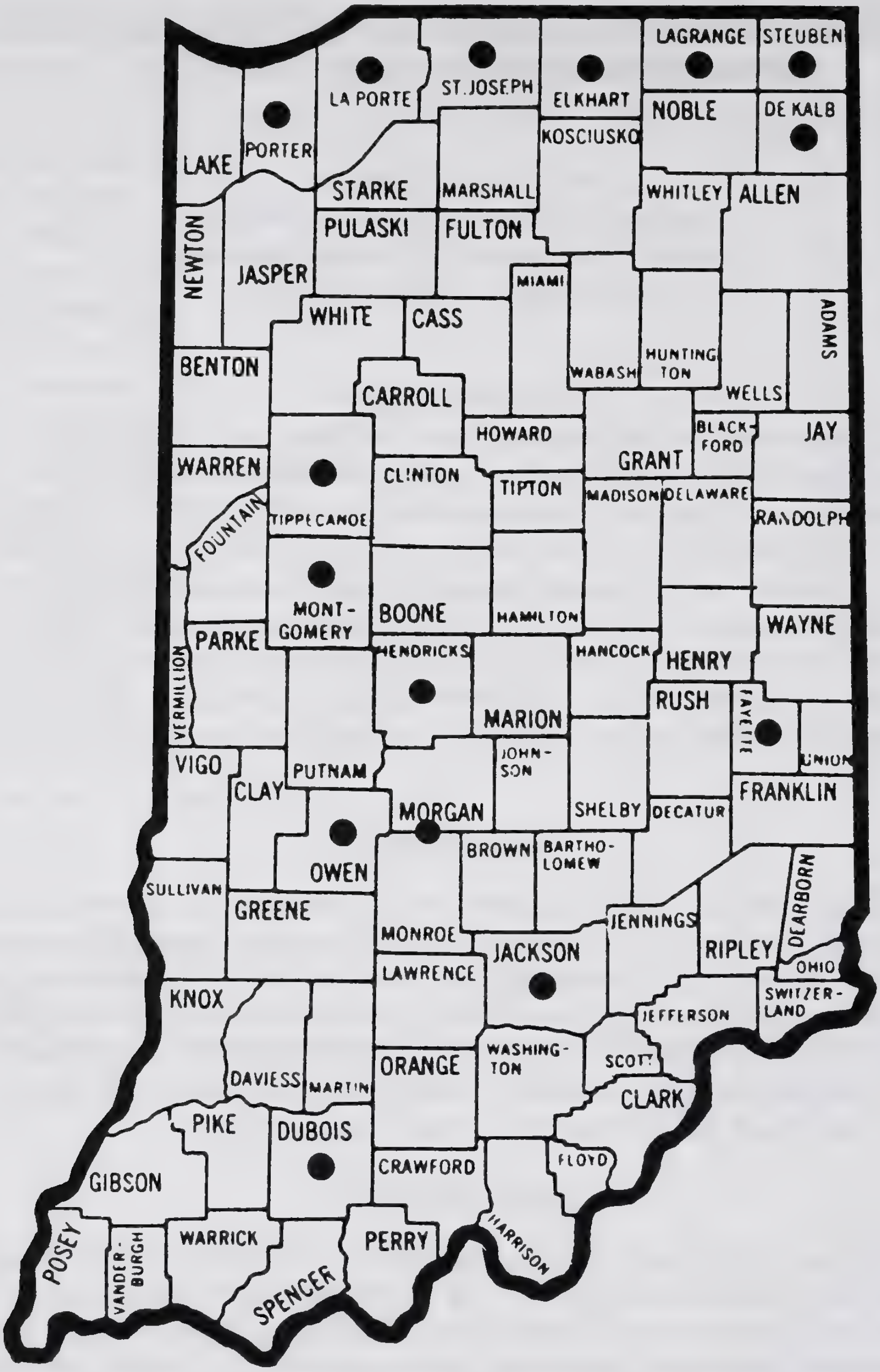

FIGURE 1. County distribution of bog bluegrass (*Poa paludigena*) in Indiana.

Bog bluegrass normally does not form free-standing solitary clumps but grows on hummocks formed by other vegetation or on saturated rotting logs that have fallen into the seepage community. Species that it characteristically associates with include skunk cabbage (*Symplocarpus foetidus* (L.) Nutt.), marsh marigold (*Caltha palustris* L.), fowl-meadow grass (*Glyceria striata (Lam.) Hitchc.),* swamp saxifrage, (*Saxifraga pensylvanica* L.), swamp betony (*Pedicularis lanceolata* Michx.), showy lady's slipper (*Cypripedium reginae* Walt.), and several sedges (e.g., *Carex hystricina* Muhl., *Carex leptalea* Wahlenb., and especially *Carex bromoides* Schkuhr).

STATUS

Charles Deam was the first to collect *Poa paludigena* in Indiana (*Deam 31117* IND). The collection was made in 1920 from a tamarack swamp in Lagrange County. Twenty years later in his *Flora of Indiana*, Deam (1940) reported the grass from only three counties, viz., Lagrange, St. Joseph, and Dubois. At the inception of the Indiana Natural Heritage Program in 1978, a total of seven historical collections of the grass had been made in the State, including all in the counties listed above plus Elkhart County. The most recent collections were made in 1946 (*Potzger 10239* BUT).

Poa paludigena was listed as extirpated (Bacone and Hedge, 1980) in Indiana until 1982, when *Poa paludigena* was rediscovered at an historical site in Dubois County (Homoya, 1983). Since then, over twenty extant populations have been discovered or rediscovered, many of them in 1988 as part of the status survey sponsored by the USFWS. Bog bluegrass is currently listed as watchlist (> 20 sites), the lowest level of official listing by the INHP.

The success at locating new sites is not due to an increase in the number of populations of bog bluegrass in recent times, but to the effort made in inventory. The species was probably overlooked in the past, primarily because of the rather inhospitable environment that it inhabits. Although bog bluegrass is truly an uncommon plant, it is not rare and could certainly be found at additional sites with further inventory efforts.

ACKNOWLEDGMENTS

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VERSAILLES STATE PARK REVISITED: TWENTY YEARS OF CHANGE IN OLD-GROWTH FORESTS OF LAUGHERY BLUFF AND DOGWOOD NATURE PRESERVES.

Marion T. Jackson
Indiana State University
Terre Haute, Indiana 47809
and
D. Brian Abrell
Indiana Division of Nature Preserves
Indianapolis, Indiana 46204

INTRODUCTION

During the summer of 1968, the least disturbed sections of the old-growth beech-maple dominated forests located in Laughery Bluff and Dogwood Nature Preserves in Versailles State Park were examined by taking full-census data for all tree species. A detailed structural analysis based on those studies was reported by Jackson and Allen (1969). In that earlier study, the stands were referred to as Jackson Woods and Potzger Woods, respectively (Lindsey, *et al.*, 1969).

Following twenty growth seasons, the portions that were the subject of the original full censuses were re-measured and comparable stand attributes were calculated. Our objectives were: 1) to compare the 1988 stand measures of density, basal area, percent importance, size-class distribution, and diversity with those taken in 1968; and 2) to document composition changes, successional trends, and gap replaement patterns over a twenty-year period.

Laughery Bluff Nature Preserve, located on a high promentory, sustained moderately high losses of canopy trees (particularly mature beeches) to windthrow during the score of years. Wind damage was substantially less in Dogwood Nature Preserve, due in part to its more sheltered location.

The landscape and ecological setting of the study sites were described in full by Jackson and Allen (1969) and will not be repeated here. Both stands are on gently rolling topography, occupy well-drained Cincinnati silt loam soils derived from Silurian and Ordovician-aged limestone, respectively. Both tracts are within the section of the State Park located south of U.S. Highway 50. Neither is often visited, maintaining their overall natural condition and lack of human-induced disturbance.

METHODS

The 1968 full census areas were resurveyed in 1988 by using the same field procedures. Points outlining the perimeters of the two study sites were relocated as closely as possible. In Laughery Bluff, the study area consisted of 17.46 acres (7.96 ha) during both surveys. The Dogwood site increased slightly in area from 6.44 acres (2.61 ha) in 1968 to 6.80 acres (2.75 ha) in 1988 as a result of boundary adjustments. In both situations, stand margins were excluded from the tallies to avoid community transitions.

TABLE 1. Changes in community composition in Laughery Bluff State Nature Preserve, 1968-1988.

	Density/Acre			**Basal Area/Acre**			**Percent Importance**		
Species	**1968**	**1988**	**% Change**	**1968**	**1988**	**% Change**	**1968**	**1988**	**% Change**
As	42.33	58.99	+39.4	12.67	23.01	+81.6	25.88	37.29	+48.7
Fg	14.32	8.88	−38.0	57.66	38.32	−33.6	32.38	21.45	−33.8
Lt	11.68	10.65	− 8.8	19.53	27.29	+39.7	14.10	17.25	+22.3
Ur	8.30	8.48	+ 2.1	2.67	2.05	−23.2	5.00	4.76	− 4.8
Jn	3.78	2.86	−24.3	6.45	7.15	+10.9	4.63	4.55	− 1.7
Fa-Fp	3.95	5.50	+39.2	2.63	4.43	+68.4	2.99	4.52	+51.2
Cf	13.23	4.52	−65.8	2.18	0.71	−67.7	6.52	2.38	−63.5
Ps	3.38	2.58	−23.7	1.19	1.30	+ 8.9	2.09	1.76	−15.8
Ns	1.72	1.03	−40.0	1.61	1.74	+ 8.1	1.51	1.26	−16.6
Sa	1.55	1.43	− 7.5	0.79	0.77	− 2.5	1.07	1.00	− 6.5
Other Species*	4.75	5.00	+ 5.3	4.29	3.35	−17.7	4.15	3.79	− 8.7
Total	108.99	109.29	− 0.3	111.67	110.12	− 1.4			

*Other species in descending order of 1988 importance: Coc, Ua, Qr, Ta, Vitis, Ccor, Ane, Ov, Ccar, Qa, Cov, At, Cg, Qmu, Ag, Ar, Aral. Three species recorded in 1968 (Jc, Fq, and Rp) were absent from the 1988 tally.

All trees 2.0 inches (5.1 cm) dbh (diameter at breast height) and greater were included in both tallies. Trees from 2.0 to 3.9 inches (5.1-9.9 cm) were counted and recorded by species. All trees 4.0 inches (10.2 cm) and larger were measured to the nearest 0.1 inch (0.25 cm) with diameter tapes. Stand attributes were calculated as follows: density per acre; relative density; basal area per acre; and relative basal area. Percent importance is the average of the relative values of density and basal area.

Species nomenclature follows Little (1953) and Gleason and Cronquist (1963) for trees and other species, respectively. Species symbols usually represent the first letters of the respective genus and species names. Variations in measures between the two studies were tested for significance by using Chi-square analysis.

RESULTS

Laughrey Bluff attribute changes. Changes in community composition during the 20-year period are summarized in Table 1. Overall, density per acre for trees > 4″ (10 cm) dbh remained static (109.0 stems in 1968 *versus* 109.3 stems in 1988); total basal area per acre declinced only 1.4% (111.7 ft^2 in 1968 *versus* 110.1 ft^2 in 1988). (Metric equivalents are 269.2 *versus* 270.0 stems/ha and 25.64 *versus* 25.27 m^2/ha).

Many individual tree species experienced marked changes in density, basal area, and percent importance (Table 1). Sugar maple (*Acer saccharum* Marsh.) increased 40% in density (χ^2 = 6.56*, 1 df) to 59 stems per average acre and nearly doubled (82% increase) in basal area per acre (χ^2 = 8.43**, 1 df). American beech (*Faqus grandifolia* Ehrh.) decreased 38% in density (χ^2 = 2.07, 1 df) and 34% in basal area (χ^2 = 6.48*, 1 df). These approximately equal but opposing changes resulted in an essentially unchanged combined percent importance for the two dominant species (57.5% in 1968 *versus* 58.7% in 1988). Sugar maple increased in density through accessions; that is, gains in basal area resulted primarily from growth of small to medium-sized surviving trees. Changes in beech attributes were due largely to windthrow and other mortality of medium-sized to large canopy individuals.

Late-seral but intolerant species (*e.g.*, tulip tree (*Liriodendron tulipifera* L.), slippery elm (*Ulmus rubra* Muhl.), black walnut (*Juglans nigra* L.), black cherry (*Prunus serotina* Ehrh.), black gum (*Nyssa sylvatica* Marsh.), and sassafras (*Sassafras albidum* (Nutt.) Nees)) decreased in density from lack of replacement of dying trees, while these species increased in basal area through the growth of remaining stems. White and green ashes combined (*Fraxinus americana* L. and *F. pennsylvanica* Marsh.) increased in density, basal area, and percent importance. None of these changes was significant.

Among the most interesting and least explicable changes were the 66% decline in density (χ^2 = 13.23**, 1 df) and the 68% drop in basal area (χ^2 = 0.99, 1 df) for flowering dogwood (*Cornus florida* L.; Table 1). Sixteen minor species collectively increased slightly in density (due largely to ingrowths of grapevine (*Vitis* spp.), oaks (*Quercus* spp.), and paw paw (*Asimina triloba* (L.) Dunal) but declined slightly in overall importance.

Dogwood Nature Preserve attribute changes. Stand attributes values for Dogwood Nature Preserve are shown in Table 2. Total stand density and overall basal area values are somewhat higher than those for Laughery Bluff (126.9 stems

TABLE 2. Changes in community composition in Dogwood Nature Preserve, 1968-1988.

	Density/Acre			Basal Area/Acre			Percent Importance		
Species	**1968**	**1988**	**% Change**	**1968**	**1988**	**% Change**	**1968**	**1988**	**% Change**
As	68.63	89.71	+30.7	23.93	40.30	+68.4	38.53	51.54	+33.8
Fg	14.29	11.76	−17.8	57.84	47.05	−18.7	30.69	23.54	−22.6
Jn	4.50	4.41	− 2.0	7.44	8.80	+14.2	5.05	5.28	+ 4.6
Fa-Fp	7.30	5.00	−31.5	5.17	7.74	+49.7	5.23	5.08	− 2.9
Lt	2.48	2.21	−10.9	4.13	4.31	+ 4.4	2.79	2.63	− 5.7
Ns	2.64	1.47	−44.3	5.24	3.96	−24.4	3.33	2.17	−34.8
Ps	3.57	1.91	−46.5	2.44	2.66	+ 9.0	2.52	1.83	−27.4
Ur	3.88	2.21	−43.0	3.12	2.06	−34.0	2.94	1.73	−41.2
Ta	1.24	1.62	−30.6	0.90	1.50	+66.7	0.90	1.23	+36.7
Ua	1.55	1.32	−14.8	1.00	1.23	+23.0	1.07	1.02	− 4.7
Other Species*	11.35	5.30	−53.3	5.37	4.83	−10.1	7.61	4.01	−47.3
Total	121.43	126.92	+ 4.52	116.58	124.44	+ 7.7			

*Other species in descending order of 1988 importance: Coc, Ccor, Cf, Sa, Vitis, Qr, Ag, Qa, Ar, Cg, Ov. Two species recorded in 1968 (Fq, Qmu) were absent from the 1988 tally.

in 1988 *versus* 109.3 in 1968 and 124.4 ft²/acre in 1988 *versus* 110.0 in 1968, respectively). (Metric equivalents are 313.4 and 270.0 stems/ha and 28.55 and 25.27 m²/ha). Changes in total density and basal area were greater (4.5% and 7.7%) than found for Laughery Bluff, but neither difference was significant (χ^2 = 0.25 and 0.53, 1df, respectively).

Sugar maple increased its dominance with a 31% increase in density (χ^2 = 6.47*, 1 df) plus a 68% increase in basal area (χ^2 = 11.20**, 1 df). Beech declined in both density (18%) and basal area (19%), but neither change was significant (χ^2 = 0.45 and 2.01, respectively). The two species combined strengthened their co-dominance from 69.2 to 75.1 percent importance during the 20 years, the 13% gain for sugar maple more than offsetting the 7% decline in beech. As is typical in many beech-maple dominated forests, young sugar maples are rapidly entering this stand, along with relatively rapid growth in size of surviving sub-canopy trees. Declines in beech resulted from the deaths of a few canopy trees.

All of the subdominant species except American basswood (*Tilia americana* L.) and the minor species collectively declined in density, none significantly. Changes in basal area were less predictable, depending upon mortality losses in comparison with growth. The subdominant walnut and ashes increased substantially in basal area through growth, despite losses in density. All subordinant species declined in percent importnce, except walnut and basswood, with the minor species collectively suffering the greatest loss, due largely to mortality in understory species.

Laughery Bluff size class changes. A size-class comparison by species reveals modest recruitment of entry-sized trees (2.0-3.9″ dbh) into the stand by both of the co-dominant species (Tables 3). Sugar maple gained 48 individuals for a 5% increase, while the 20 new beeches represent a 111% increase in young saplings. The populations of all other species sustained substantial losses from the 2.0-3.9″ size class except hackberry (*Celtis occidentalis* L.) and the minor species collectively.

For the size classes greater than 4.0″ dbh, sugar maple and beech experienced contrasting changes (Table 3). Subcanopy sugar maples (4.0-11.9″ dbh) increased in number by 30%. Subcanopy beech remained unchanged at only 8 individuals, compared to 904 similar-sized sugar maples in the 1988 census. Sugar maple increased threefold in the 12-19.9″ dbh class and by fivefold in the 20-27.9″ dbh class. Medium-sized and large beech declined by 59%, 41%, and 40% in the 8-inch size classes, respectively, ranging from 12-36″ dbh.

In 1968, beech represented 65% (220 of 329) of the canopy trees greater than 20″ dbh. By 1988, beech represented only 45% (138 of 306), for a net loss of 82 canopy trees (4.6/acre) in 20 years (χ^2 = 19.72**, 1 df). An average loss of one canopy tree per acre every four years released many of the existing trees of other species.

In addition to the gains in sugar maple mentioned above, tulip tree increased by 57% (from 61 to 96 incidivuals; χ^2 = 20.08**, 1 df) and black walnut by 60% (from 20 to 32 individuals; χ^2 = 7.20**, 1 df) in size classes greater than 20″ dbh. Both of these intolerant species lost individuals in all size classes below 20″ dbh as the light gaps created by beech mortality began closing above them. Tulip tree declined from 169 to 108 small trees (36% loss; χ^2 = 22.02**, 1 df), while black walnut dropped from 48 to 18 (63% loss; χ^2 = 18.75**, 1 df). All other species

TABLE 3. Size-class comparison for Laughery Bluff Nature Preserve, 1968 versus 1988.

		Size Classes						Total	Total
Species	Year	2-3.9	4-11.9	12-19.9	20-27.9	28-35.9	36-43.9	> 4″	> 2″
As	68	976	699	38	2	—	—	739	1715
	88	1024	904	114	10	2	—	1030	2054
Fg	68	18	8	22	107	100	13	250	268
	88	38	8	9	63	60	15	155	193
Lt	68	26	73	70	49	11	1	204	230
	88	18	35	55	59	32	5	186	204
Jn	68	2	11	35	20	—	—	66	68
	88	—	3	15	29	3	—	50	50
Fa-Fp	68	59	51	14	3	1	—	69	128
	88	23	65	21	8	2	—	96	119
Ur-Ua	68	155	151	11	7	—	—	169	324
	88	82	141	15	2	1	—	159	241
Ns	68	7	20	5	4	1	—	30	37
	88	1	7	6	2	3	—	18	19
Ps	68	41	53	5	1	—	—	59	100
	88	20	40	3	2	—	—	45	65
Cf	68	79	231	—	—	—	—	231	310
	88	67	79	—	—	—	—	79	146
Coc	68	18	10	3	2	—	—	15	33
	88	43	13	4	2	—	—	19	62
Other Spp.	68	188	53	12	6	1	—	72	260
	88	271	68	7	4	1	81	352	
Total	68	1569	1360	215	201	114	14	1904	3473
	88	1587	1363	249	181	104	21	1918	3505

collectively remained essentially constant (26 *versus* 28) in the larger size classes (an 8% overall gain). The minor species collectively lost 190 individuals (1166 *versus* 976) from their populations for a 16% decline ($\chi^2 = 30.96^{**}$, 1 df). Many of these losses resulted from the high mortality of elms (*Ulmus rubra* Muhl. and *U. americana* L.) and flowering dogwood (*Cornus florida* L.) from the smallest size classes.

When comparing totals for all species, the size classes below 12″ dbh increased by only 21 stems (2929 *versus* 2950). Sugar maple increased from a total of 57% to 65% of all small individuals from 1968 to 1988. All species collectively increased by only 11 stems (544 *versus* 555) in size classes above 12″ dbh, for a remarkably constant overall stand density. Sugar maples' contribution to that total increased from 7.4% in 1968 to 22.7% in 1988. Meanwhile, beech declined from 44.5% to 26.5% of the canopy trees.

Dogwood Nature Preserve size class changes. Sugar maple experienced a 32% loss in young saplings (2-3.9″ dbh ($\chi^2 = 59.04^{**}$, 1 df), while beech doubled its modest number of two individuals (Table 4). The collective population of all species other than the two dominants sustained an even greater loss of 63% (182 *versus* 68), primarily from mortality in understory species, which never reach canopy size.

In size classes greater than 4.0″ dbh, sugar maple increased 39% from a total of 442 to 616 ($\chi^2 = 68.49^{**}$, 1 df), while beech declined slightly (13%) from 92 to 80 stems ($\chi^2 = 1.57$, 1 df). Subcanopy sugar maples (4.0-11.9″ dbh) increased 31% whereas canopy maples increased 177% (from 26 to 72 stems) due to advancements from smaller size classes. Canopy beeches (> 12″ dbh) sustained little windthrow and only minor mortality for a net loss of 9 trees (84 *versus* 75), only 1.3 per acre during the 20-year period.

Collectively, black walnut, the ashes, and tulip tree increased modestly in numbers of canopy trees from a total of 48 in 1968 to 58 in 1988 (a 21% change). All three species collectively declined in number of subcanopy individuals from 55 to 21 ($\chi^2 = 21.01^{**}$, 1 df). All minor species had a combined gain of only 11 individuals (28% increase) in the canopy size classes, while populations of subcanopy species were reduced from a total of 286 to only 112, a 61% decline. Dogwood declined precipitously from a total of 84 to only 26 stems in 1988, a 69% loss ($\chi^2 = 40.05^{**}$, 1 df).

In 1968, beech and sugar maple totaled 88 of 116 canopy trees (76%) in sizes greater than 20″ dbh. By 1988, they represented 77 of 117 canopy trees (68%) for a net loss of only 11 stems ($\chi^2 = 1.38$, 1 df). Increased combined dominance from 69 to 75% resulted primarily from small maples entering the stand, plus net growth of larger trees.

When totals for all species are compared (on an acreage-adjusted basis), subcanopy individuals declined 24% from 210.1 per acre to 159.7 per acre ($\chi^2 = 12.09^{**}$, 1 df). Smaller canopy trees (12-19.9″ dbh) increased 63% from 12.7 to 20.7 stems per acre ($\chi^2 = 5.04^{**}$, 1 df). Large canopy trees over 20″ dbh remained essentially static (18.0 versus 16.9 per acre).

Size class changes by species group. Examination of size class changes for selected groups of species reveals some interesting patterns (Table 5). Xerophytic species (mostly *Quercus* and *Carya*) declined in number in most size classes

TABLE 4. Size-class comparison for Dogwood Nature Preserve, 1968 versus 1988.

		Size Classes						Total	Total
Species	Year	2-3.9	4-11.9	12-19.9	20-27.9	28-35.9	36-43.9	> 4″	> 2″
As	68	586	416	12	10	4	—	442	1028
	88	400	544	58	6	8	—	616	1016
Fg	68	2	8	10	30	36	8	92	94
	88	4	5	12	30	23	10	80	84
Jn	68	—	2	20	7	—	—	29	29
	88	—	1	19	10	—	—	30	30
Fa-Fp	68	9	33	11	3	—	—	47	56
	88	—	15	9	9	2	—	35	35
Lt	68	2	9	3	2	2	—	16	18
	88	—	5	5	2	1	1	14	14
Ns	68	2	7	2	7	1	—	17	19
	88	—	1	3	2	3	—	9	9
Ur-Ua	68	10	25	7	3	—	—	35	45
	88	—	10	15	—	1	—	26	26
Ps	68	1	15	8	—	—	—	23	24
	88	—	1	10	2	—	—	13	13
Cf	68	64	20	—	—	—	—	20	84
	88	17	9	—	—	—	—	9	26
Coc	68	4	4	—	—	1	—	5	9
	88	—	2	1	1	1	—	5	5
Other Spp.	68	89	45	9	1	1	—	56	145
	88	51	21	9	2	1	—	33	84
Total	68	769	584	82	63	45	8	782	1551
	88	472	614	141	64	40	11	870	1342

except for entry-sized trees in Laughery Bluff. Overall these species lost half of their stems in Dogwood Preserve. Hydrophytic species likewise dropped substantially in Dogwood Preserve and slightly in Laughery Bluff in most size classes. Conversely, mesophytic species (not shown in Table 5) collectively changed very little in most size classes or in overall totals. These changes reflect the mesic conditioning that is widesperead in beech-maple stands in the Midwest.

Understory species declined significantly overall in both stands, primarily due to high losses of flowering dogwood. Increases in 2-4″ stems in Laughery Bluff resulted from invasion of paw paw into mesic light gaps and large sinks. Lianas (predominantly *Vitis* sp.) increased only slightly in Dogwood Preserve through growth of existing stems, while rapid invasion into canopy openings doubled the vine population in the Laughery Bluff stand.

Yearly changes for key species. Table 6 summarizes the average annual percentage change in stems and basal area for key species during the 20-year period. Sugar maple increased more than any other species in both stands. At an average compounded increase in density in Laughery Bluff of 1.8%/year, sugar maple would be expected to double in numbers in less than 40 years; at a sustained basal area increase of 4.1%/year, the species would double in that measure in about 16 years. Beech declined in density and basal area at nearly 2%/year in Laughrey Bluff and at about 1% per year in Dogwood Preserve. These opposing changes for the co-dominants, if continued at these rates for another 20 years, would result in predominately sugar maple stands with beech relegated to a subdominant species.

Ashes are increasing in basal area in both stands at rates approaching that of sugar maple. Tulip tree and black walnut are both declining in numbers but increasing in basal area through incremental growth of medium-sized and larger trees. Elms are rapidly losing basal area as diseases afflicting larger individuals of those species continue to exact their toll. Flowering dogwood, with declines of around 3% for both measures in both stands, has limited tenure in these nature preserves, if these trends continue. Such loss rates would essentially extirpate that species within another 20 years.

Diversity changes. Species richness of large woody plants in Laughery Bluff was 33 in all size classes in 1968. Five of these were present only in the 2-3.9″ class. Six species from the 1968 survey were not encountered at sizes > 2″ dbh in 1988: butternut (*Juglans cinerea* L.), blue ash (*Fraxinus quadrangulata* Michx.), black locust (*Robinia pseudo-acacia* L.), poison-ivy (*Rhus radicans* L.), red mulberry (*Morus rubra* L.), and rock elm (*Ulmus thomasii* Sarg.). Species new to the area in 1988 include: green ash (*Fraxinus pennsylvanica* Marsh.), red maple (*Acer rubrum* L.), and devil's walkingstick (*Aralia spinosa* L.). The species richness now stands at 30.

Dogwood Preserve contained 27 large woody species in 1968 and 24 in 1988. The three species absent in 1988 were: blue ash, chinkapin oak (*Quercus muehlenbergii* Engelm.), and paw paw (*Asimina triloba* (L.) Dunal.). No species new to the stand was encountered.

DISCUSSION

Although the two stands under consideration are geographically close, occur on similar topography and soils, and have the same co-dominant species, their

TABLE 5. Comparison of size-class changes for selected groups of species 1968 versus 1988.

		Size Class						
Species Group	2-4	4-12	12-20	20-28	28-36	>36	Total >4″	Total >2″
Xerophytic Species								
Dogwood 1968	9	13	7	—	—	—	20	29
1988	3	4	5	2	—	—	11	14
Laughery 1968	4	6	5	4	1	—	16	20
1988	11	7	2	3	1	1	14	25
Hydrophytic Species								
Dogwood 1968	22	40	10	10	2	—	62	84
1988	10	16	21	3	4	—	44	54
Laughery 1968	217	184	19	14	1	—	218	435
1988	202	179	25	6	4	—	214	416
Understory Species								
Dogwood 1968	97	36	—	—	—	—	36	133
1988	23	10	—	—	—	—	10	33
Laughery 1968	155	245	—	—	—	—	245	400
1988	172	95	—	—	—	—	95	267
Lianas								
Dogwood 1968	35	—	—	—	—	—	0	35
1988	31	5	—	—	—	—	5	36
Laughery 1968	82	6	—	—	—	—	6	88
1988	139	13	—	—	—	—	13	152

TABLE 6. Average yearly percentage change in stem density and basal area for key species.

	% Change in Stems		% Change in Basal Area	
Species	**Laughery**	**Dogwood**	**Laughery**	**Dogwood**
As	+1.83	+1.54	+4.08	+3.42
Fg	−1.90	−0.89	−1.68	−0.93
Lt	−0.44	−0.54	+1.99	+0.22
Jn	−1.21	−0.10	+0.53	+0.91
Fa-Fp	+1.96	−1.58	+3.43	+2.49
Ur-Ua	−0.29	−1.75	−1.73	−1.01
Cf	−3.29	−2.88	−3.38	−3.10
All Species	+0.04	+0.23	−0.07	+0.34

bedrock geology, history of disturbance, and present-day composition are somewhat different.

Laughery Bluff occurs on Silurian limestone, which is subject to karst formation, creating frequent sinks of varying size and configuration. These sinks, with unstable slopes and internal drainage create thinner canopy along their rims and accumulate fertile alluvium in their bottoms. Improved light availability and soil conditions favor establishment and thrifty growth of such species as tulip tree, black walnut, white and green ash, and slippery elm. The stand attributes values (Table 1) reflect the improved conditions for these subdominant species. The collective percent importance for these five species is 31.1% (up from 26.7% in 1968). Beech and sugar maple are definitely co-dominant but total only 58.7 percent importance. Minor cutting of canopy trees in the 1930's (Jackson and Allen, 1969) has also favored the continuance and growth of subdominant species, as the stand is still adjusting to that disturbance and the stress of windthrow of several canopy beeches during the past twenty years.

Dogwood Preserve, which is found on Ordovician limestone, has about the same relief as Laughery Bluff, but the drainage is external through surface ravines. Disturbance from cutting was slight and prior to 1930 (Stearns, 1956). Recent windthrows occurred at only one third the frequency (on a per acre basis) of those at Laughery Bluff. Consequently, the subdominant species discussed above total only 14.7 percent importance (down from 16.9% in 1968). Beech and sugar maple are overwhelmingly the co-dominant species at 75.1 percent importance. Interestingly, the co-dominant and subdominant species have combined totals of exactly 89.8 percent importance in each stand; 1968 totals were 84.2 and 85.2 percent, respectively. Adjustments among the relative contributions of these seven species have kept total stand density and basal area values remarkably constant during the past twenty years, despite substantial losses of canopy beeches. Perhaps this reflects the resilience of old-growth forest communties, a documented example of the concepts of dynamic equilibrium and interspersion of a mosaic of community dominants.

Rapid increases in sugar maple in beech-maple dominated stands, apparently at the expense of beech, has been frequently documented (*e.g.*, Abrell and Jackson, 1977; Dunn and Jackson, 1979; Lindsey, *et al.*, 1969). These two stands also follow that pattern. During the past twenty years, the co-dominant species reversed positions at Laughery Bluff as a result of a gain in importance for sugar maple of 12.2%, while beech dropped 10.9% (Table 1). In Dogwood Preserve, sugar maple increased its dominance with a 13% gain, while beech decreased 7.2% (Table 2). These changes are a result of the rapid ingrowth of large numbers of sugar maple saplings into the 4-11.9″ size class plus advancements of fewer survivors into large size classes (Tables 3,4) along with deaths of canopy beeches. Entry of sugar maple into the 2-4″ size class has slowed or reversed; Laughery Bluff increased by only 5% (Table 3); Dogwood Preserve had a 32% decline. These numbers in part reflect differences in the size and number of canopy openings initially as well as differential survival rates of these young trees in low light conditions.

Prolific reproduction of sugar maple may be viewed as a biotic term insurance for maintaining canopy co-dominance for the species. Sugar maple sustains high mortality among smaller size classes, but survivors are also capable of reaching the canopy in a shorter time than can beech, if favorable conditions occur. Conversely, sugar maples apparently reach great age (> 200 years) much less frequently than do beeches. The slower growing beech have the potential for longer residence time as canopy individuals, once they reach large size. By employing contrasting life history strategies, the two species may co-dominate for long periods, each waxing and waning in response to change in the importance of the other and to environmental perturbations lasting a few decades to a century or more. In recent decades, beech has sustained heavy mortality from windthrow in many Midwestern stands, augmenting the natural tendency for sugar maple to increase.

The average yearly changes in density and basal area for certain species (Table 6) give reason for concern about the demography of some populations within these stands. Although such average yearly change rates are most likely not linear over long periods, consistent declines of even 1% per year would eliminate a species from the stand in less than a century. Flowering dogwood has decreased in both density and basal area at rates averaging more than 3% per year. These great population reductions were subjectively apparent to us upon first entering the stands for the 1988 study.

The authors have noted dieback and mortality of dogwood in a number of mesic stands in southern Indiana but had no quantitative documentation of population depletion before this study. Dogwood is well known to weather drought conditions poorly and as a species which concentrates calcium (Fowells, 1965). McCune, *et al.* (1987) have a monitoring study to determine the impact of mining activity surrounding Hemmer Woods on dogwood populations. More such studies on a long-term basis for a number of species are needed to determine causation of declines such as we noted for flowering dogwood from our twenty-year comparison. If the loss rates of past years are continued for another two decades, flowering dogwood will be essentially extirpated from both of these stands. Perhaps, Dogwood Nature Preserve should be renamed.

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PSYCHOLOGY

Chair: Samuel B. Schnitzer
Department of Psychology
Indiana State University
Terre Haute, IN 47809

Chair-Elect: Kathryn N. Black
Dept. of Psychological Sci.
Purdue University
West Lafayette, IN 47907

ABSTRACTS

Familiarity With A Male's Flank Gland Odor In Mate Selection In Female Hamsters. Pat Brown, Eric Lis, and Bob Fischer, Dept. of Psychological Science, Ball State University, Muncie, IN 47306.—There is little direct evidence that the hamster's flank gland effectively functions in intermale aggression. The odors of this gland do convey information concerning a male's familiarity (identity) and dominance to sexually receptive females and may play a role in mate selection. Two experiments evaluated the ability of flank odors to influence a female's choice of a mate. The first experiment indicated that a female would selectively mate with a tethered male whose flank odors were familiar over a male whose secretions she had not previously encountered. The second experiment simultaneously varied dominance and familiarity in order to judge the relative effectiveness of each stimulus. Females exhibited no consistent mating preference. The males did differ in the amount of sexual contact with females. Familiarity with a male's flank odors is an important factor in mate selection. When familiarity is confounded with status, the females may judge the stimuli as being equally attractive or are, perhaps, confused by the unnatural combination of stimuli and are thus unable to exhibit a clear preference.

Karl Pearson, Correlations, and Inherited Traits: The Use and Misuse of Statistics. Walter Hartmann, Purdue University Calumet, Hammond, IN 46323.—Pearson (of the correlation coefficient, Director of the Galton Laboratory, Fellow of the Royal Society, etc.) together with Margaret Moul issued a massive study in 1925 warning the British government against permitting immigration of a certain group. In 121 pages with numerous tables summarizing all kinds of mental, environmental, and physical tests, Pearson and Moul "prove" the inherent physical, intellectual, cultural, and moral inferiority of this group—Eastern European Jews. This paper adumbrates Pearson and Moul's assumptions and methods. Their almost comical fallacy is discussed in the light of their misunderstanding of genetics, and of what statistics can and can not do—errors not uncommon to this day.

Is the Self-Defeating Personality Disorder a Viable Diagnosis? Kathleen M. Hilton and Paul W. Horn, Department of Psychology, Indiana State University, Terre Haute, IN 47809.—This study considers the Self-Defeating Personality Disorder (SDPD) in relation to the other DSM-III personality disorders. The prevalence of personality disorders was assessed using the Millon Clinical Multiaxial Inventory (MCMI) and a newly designed scale for measuring SDPA

(H-SDPD), both of which were administered to 168 subjects. Of those classified as self-defeating using the H-SDPD criteria, 95% met the MCMI criteria for one or more other personality disorders. In addition, over 40% of the self-defeating subjects in this study met the criteria for diagnosis as schizoid-asocial, avoidant, dependent-submissive, passive-aggressive negativistic, and/or borderline, suggesting that SDPD may be a more generalized construct. The findings also showed both striking similarities and significant differences in personality disorders between self-defeating males and self-defeating females.

Personality Dimensions and Obesity. PAUL W. HORN and KATHLEEN M. HILTON, Department of Psychology, Indiana State University, Terre Haute, IN 47809.—This study examines the personality profiles of members of a nationally recognized group for overweight individuals. The prevalence of personality disorders was assessed using the Millon Clinical Multiaxial Inventory (MCMI). The findings from a normative sample (N = 91) and the overweight sample (N = 91) indicated significant differences between these groups on both personality factors and Axis I classifications. More specifically, differences were found in the histrionic, compulsive, passive-aggressive, anxiety, and hypomanic areas. Our analyses showed that these areas were in a direction opposite to what popular belief and previous research would lead one to expect. In addition our data suggest the possibility of personality differences associated with magnitude of obesity.

A New Four-Stage Theory of Grief as a Response to Loss. BARBARA KANE, Indiana State University, Terre Haute, IN 47809.—Grief as a response to loss is discussed and a new four-stage theory of grief response is proposed. The cognitive theory of Piaget is used to explain the process. The new theory has the characteristics indicated by Flavell to be necessary for stage theories: invarient sequence, gradual development, subsumation and integrity. In Stage One, Anesthesia, the griever ignores the loss. During Stage Two, Sensitivity, the loss is experienced. When the griever is in Stage Three, Deliberation, the loss is understood. In Stage Four, Adaptation, the griever changes with the loss. Grief work related to each stage is discussed.

The Case for Psycho-Optometry: A Selective Review of the Literature. ROGER L. TERRY, Department of Psychology, Hanover College, Hanover, IN 47243.—This paper selectively reviews the accumulating research demonstrating the role of psychological variables in various areas of optometric concern. There is mounting evidence that psychological factors are important influences on persons' decisions to seek out professional eye care and on the success of patients' adaptation to various types of visual correctives. Attention is directed to the writer's research on the psychological side effects of frame glasses and contact lenses. The construct of a spectacle image component of the self concept is advanced to account for the negative psychological effects of framed spectacles and the positive effects of contact lenses. Suggestions are offered of fertile areas for future investigation.

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SENSATION SEEKING AND FAMILIAL ALCOHOLISM: EVIDENCE FOR DEVELOPMENTAL DIFFERENCES IN TWO ALCOHOLIC SUBGROUPS

Thomas D. Shazer
Center for Forensic Psychiatry
P.O. Box 2060
Ann Arbor, Michigan 48106
and
Samuel B. Schnitzer
Department of Psychology
Indiana State University
Terre Haute, Indiana 47809

ABSTRACT: Sensation seeking is a personality trait which has been found to be stronger among alcoholics than among nonalcoholics and which correlates negatively with age in various populations. The present study compared correlations of age and sensation seeking between a group of alcoholics meeting criteria for familial alcoholism and another group which did not meet these criteria. A total of eight different scores were taken from subjects' scores on the Sensation-Seeking Scale, fifth revision, and while seven of these scores were significantly negatively correlated with age in the nonfamilial sample, only two of these were correlated with age in the familial sample. Since this developmental consistency in the familial group is anomalous and since there are theoretical reasons for believing that sensation seeking is etiologically related to alcohol abuse, this study's findings suggest that stability of sensation seeking over time might be an etiological factor specific to familial alcoholism. The implications of this possibility for research and treatment are discussed.

INTRODUCTION

Zuckerman and his colleagues (e.g., Zuckerman, *et al.*, 1964, 1972, 1980) have defined a personality construct which they refer to as sensation seeking. Sensation seeking is defined as the behavioral expression of the optimum level of arousal construct (Zuckerman, *et al.*, 1964); that is, the extent to which persons engage in different types of behavior in order to maintain a preferred degree of arousal. Age has consistently been found to correlate negatively with sensation in different populations (Zuckerman, 1979).

Numerous studies (Galizio, *et al.*, 1983; Huba, *et al.*, 1981; Kilpatrick, *et al.*, 1982; Schwartz, *et al.*, 1978; Segal, *et al.*, 1980; Zuckerman, *et al.*, 1972) have revealed a relatively higher degree of sensation seeking (that is, the tendency to behave so as to maintain a relatively higher degree of arousal) in alcoholic samples in comparison to nonalcoholic samples. In addition, several of these studies (Galizio, *et al.*, 1983; Huba, *et al.*, 1981; Schwartz, *et al.*, 1978; Segal, *et al.*, 1980; Zuckerman, *et al.*, 1972) have revealed a particularly strong expression of disinhibition, a tendency to maintain arousal through the circumventing of various sources of behavioral control, in alcoholics vis-á-vis nonalcoholics. It has been suggested (Schwartz, *et al.*, 1978) that alcoholics might drink in order to maintain a high level of arousal and that alcohol is effective in this regard because it is disinhibitory, both in terms of depressing cortical centers of control and in terms of cultural norms which permit disinhibited behavior among intoxicated persons.

In each of these studies, alcoholism was treated as a unitary construct. However, alcoholism may not refer to a single diagnostic entity, but instead it can be divided into different subtypes with distinct clinical pictures (Goodwin, 1979). Goodwin (1979) proposed an alcoholic classification, which he designated the familial subtype of the disorder. Familial alcoholism is defined as a type of alcohol abuse in which the patient has a family history of alcoholism, experiences an early onset of the disorder, exhibits relatively severe symptoms, and is free from other severe pathology. Goodwin suggested that familial alcoholism occurs only among males. Given the validity of the alcoholic subtype assumption, it is possible that members of the different subtypes would differ with respect to any number of variables. One possibility is that familial and nonfamilial alcoholics differ in the relationship between age and sensation seeking. The present study examines the relationship between age and sensation seeking in a sample of alcoholics divided into subsamples composed of those meeting Goodwin's (1979) criteria for the familial subtype of alcoholism and of those who do not.

METHODS

Subjects. The subjects in this study were 62 male inpatients from the Alcohol Treatment Program at the Veteran's Administration Medical Center in Brecksville, Ohio. Participation was voluntary. The only incentive offered to prospective participants was the opportunity to receive feedback on their performance on a test battery administered as part of the study. All volunteers were informed of the potential risks and benefits involved in participation. Potential volunteers were excluded only if they exhibited symptoms suggesting that they suffered from organic impairment. Three potential subjects were excluded on this basis.

Based on Goodwin's (1979) definition, subjects were assigned to the familial group, if they met the following operational criteria for the subtype: 1) familial subjects had two or more biological relatives who likely suffered from a drinking problem; 2) they either received treatment for the disorder prior to the age of 30 or else exhibited severe impairment in two or more functional areas (e.g., lost several jobs due to intoxication at work and had a divorce and estrangement from other family directly related to drinking) prior to that age; and 3) they were free from psychotic or major mood symptoms and reported a negative history for such symptoms, treatment with neuroleptics or lithium, etc. Of the 62 subjects studied, age data was recoverable for 57. Thirty-seven were assigned to the familial group, and 20 were assigned to the nonfamilial group.

Materials. The data reported in this study were collected using the Familial-Nonfamilial Drinking Questionnaire (FNF; Shazer, 1988) and the Sensation-Seeking Scale, fifth revision (SSS-V; Zuckerman, *et al.*, 1978). The FNF is a paper and pencil device created especially for use in the present research and was eventually administered in a structured interview format. It gathers family and drinking

TABLE 1. Correlations of age and sensation-seeking variables in familial and nonfamilial groups.

Sensation-Seeking Variables	Combined (n=57) r	Groups Nonfamilial (n=20) r	Familial (n=37) r
Total	−0.436***	−0.545**	−0.244
Total (Alcohol-Corrected)	−0.446***	−0.558**	−0.262
Total (Disinhibition-Corrected)	−0.417**	−0.486*	−0.290*
Disinhibition	−0.285*	−0.487*	−0.019
Disinhibition (Alcoholic Corrected)	−0.325**	−0.544**	−0.009
Thrill and Adventure Seeking	−0.439***	−0.401*	−0.397**
Experience Seeking	−0.387**	−0.550**	−0.236
Boredom Susceptibility	−0.020	−0.056	−0.100

* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

history data relevant to the criteria for familial alcoholism. The SSS-V is a factor-analytically derived, 40-item paper and pencil device which yields a total sensation seeking score as well as scores for four subscales. The factors which the subscale scores reflect include disinhibition (Dis), as described above. Another factor is thrill and adventure seeking (TAS), the preference for maintaining arousal through speed and physically dangerous activities. The SSS-V also measures experience seeking (ES), the preference for maintaining arousal through exposure to novel situations and involvement in deviant groups. A final SSS-V scale is boredom susceptibility (BS), the extent to which persons experience diminished interest/arousal following repeated exposure to activities.

Statistical procedure. Pearson product-moment correlations were computed between age and all sensation-seeking variables. Bartlett's Box-F statistics, a test of homogeneity of variance, were also computed for age and sensation-seeking variables. Separate analyses were conducted for the entire sample as well as for the familial and nonfamilial subsamples. In addition to total SSS-V scores and subscale scores, three corrected scores were employed. Both total SSS-V and Dis scores were corrected for the presence of three alcohol related items on the Dis subscale by subtracting the contribution of these items from the original scores. These corrected scores were used to permit examination of correlations of age with total SSS-V and Dis scores that were independent of the effects of possible differential correlations of age with drinking itself that might be present in the different subsamples. In addition, total SSS-V scores were corrected by subtracting the contribution of Dis items from them. This was done to permit the examination of correlations of age with total SSS-V items independent of the effects of possibly differential correlations of age with Dis. Given the strong relationship between Dis and drinking, which has been reported in the literature, such a procedure seemed desirable.

RESULTS

The correlations of age and sensation-seeking variables obtained in the combined sample and in the familial and nonfamilial subsamples are presented in

TABLE 2. Differences in homogeneity of age and sensation-seeking variables between familial and nonfamilial groups.

Variables	**Familial (n = 39)** s^2	**Nonfamilial (n = 23)** s^2	**Bartlett's F**	***p***
SSS-V				
Total	29.16	30.69	0.208	0.648
Total (Alcohol-Corrected)	26.73	26.63	0.066	0.798
Total (Disinhibition-Corrected)	19.80	17.89	0.030	0.863
Disinhibition	4.20	4.24	0.192	0.661
Disinhibition (Alcohol Corrected)	2.49	2.43	0.209	0.648
Thrill and Adventure Seeking	5.76	8.70	0.184	0.367
Experience Seeking	4.12	2.62	0.798	0.372
Boredom Suseptibility	2.79	1.85	0.925	0.336
Age	73.96[a]	141.61[b]	2.677	0.102

[a] n = 37.

[b] n = 20.

Table 1. All of the sensation-seeking variables were significantly correlated with age in the combined and nonfamilial groups except for boredom susceptibility. It is worth noting that the alcohol-correlated total SSS-V and Dis scores in two of the groups were more strongly correlated with age than were the uncorrected scores. This suggests that the significant correlations obtained in the combined and nonfamilial groups were not merely artifacts of a strong correlation between age and drinking itself. It is also worth noting in Table 1 that in both the combined and the nonfamilial groups the magnitude of the correlation of age with uncorrected total sensation-seeking scores is greater than the correlation of age with Dis-corrected total scores. The size of this difference is greater in the nonfamilial than in the combined group.

In contrast to findings in the combined and nonfamilial groups, age correlated significantly with only two sensation-seeking variables in the familial group. One of these correlations was obtained with Dis-corrected total sensation-seeking scores. Correlations of age with total scores and with alcohol-corrected total scores were not significant in this group. A particularly noteworthy finding was the virtual absence of correlations of age with both Dis and alcohol-corrected Dis scores in the familial group.

Before it is possible to interpret these data as reflecting actual relationships between age and sensation-seeking, it is necessary to determine whether the obtained correlations were statistical artifacts. Specifically, the small correlations observed in the familial group vis-á-vis the nonfamilal group could have been a result of a relatively restricted range of values in the familial group. To determine whether this was the case, Bartlett's Box-F analyses were computed for age and for all scores on the sensation-seeking variables, in order to assess the significance of group differences in homogeneity of variance (Table 2). Visual inspection of the variances obtained reveals very small absolute between-groups differences in the magnitude of variances for all variables except age. The F values obtained were all nonsignificant, and only the value obtained for age approached significance ($p < 0.102$). Thus, it appears that a relatively restricted range of sensation-seeking scores in the familial group cannot account for the comparatively small correlations obtained within it. While the between-groups difference in variances of subjects' ages was not statistically significant, the absolute value of the age variance in the familial group was rather small compared to that observed in the nonfamilial group and could have been, in part, responsible for the relatively small correlations in the familial group. However, two significant correlations were obtained within the familial group. It appears, therefore, that a relatively restricted range of ages among the familial alcoholics cannot entirely account for the comparatively small correlations obtained with this subsample.

DISCUSSION

The results of this study suggest that, in general, nonfamilial alcoholics' sensation seeking diminishes with age. They are similar to other, nonalcoholic, persons in this respect (Zuckerman, 1979). By contrast, while familial alcoholics' sensation seeking does diminish with age to a limited extent, this effect is not very strong. They are different from other, nonalcoholic, groups in this respect. Furthermore, the relationship between sensation seeking and age is virtually absent with regard to disinhibition, the sensation-seeking variable most strongly related to alcohol abuse (Galizio, *et al.*, 1983; Huba, *et al.*, 1981; Schwarz, *et al.*, 1978; Segal, *et al.*, 1972; Zuckerman, *et al.*, 1972). Thus, it may be that familial alcoholics differ from other alcoholics and from nonalcoholics specifically in terms of their disinhibition remaining stable over time. This possibility seems particularly compelling, since age correlations with total sensation seeking were significant for the Dis-corrected scores in the familial group but not for the scores that were not corrected for Dis. The lack of a relationship between age and sensation seeking in general among familial alcoholics might be a function of the lack of a relationship between disinhibition and age.

These results have obvious implications for research. Since familial and nonfamilial alcoholics differ in terms of the relationship between age and sensation seeking, research using unselected alcoholic samples in which sensation seeking is under investigation could well be confounded by sample characteristics of age and proportion of familial and nonfamilial subjects. Also, research investigating any variable related to sensation seeking could potentially be similarly confounded. An example of this exists within the data from the present study. If this investigation had examined the relationship between age and sensation seeking in alcoholics generally, the results would have suggested a negative correlation with age for alcoholics as a whole. At least some future research with alcoholics might well benefit from screening subjects for alcoholic subtype.

The results also have clinical implications. Since familial alcoholics apparently remain strong disinhibitors throughout their lives, if sensation seeking generally and disinhibition in particular are in fact etiologically related to alcohol abuse among familial alcoholics, it seems that interventions with familial alcoholics should address the sensation-seeking factor. If, for example, sensation seeking has a biochemical basis, as has been suggested (Zuckerman, *et al.*, 1980), perhaps pharmacologic interventions could be developed to change the biochemical factors involved. It might also be that specific expression of global sensation seeking are amenable to the effects of learning. For example, disinhibitors could possibly be trained to meet their sensation-seeking needs through an alternative modality, such as experience seeking. Because of the stability of sensation seeking over time among familial alcoholics, any such intervention would have to continue throughout the patient's life or else lead to permanent changes. Such interventions would be specific to familial alcoholics, permitting the development of intervention strategies specific to the needs of nonfamilial alcoholics as well.

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CROSS-CATEGORY DIFFERENCES IN THE AVAILABILITY OF PERCEPTUAL AND SEMANTIC INFORMATION

Walter F. Wagor
Department of Psychology
Indiana University East
Richmond, Indiana 47374

INTRODUCTION

When people make decisions about the category membership of pairs of pictured objects (respond "yes," if both objects are members of the same category), providing them with a category label in advance, that is, a prime, allows the formation of an internal representation of the category that facilitates decisions for both semantic and color categories (Duncan and Kellas, 1978; Guether and Klatsky, 1977; Rosch, 1975a, b). The representations of color categories are theorized to provide more concrete physical information than those of semantic categories as evidenced by the fact that the prime still facilitates response to color categories under physical identity instructions (respond "yes," only if the two pictures are physically identical), while the prime has no effect on decision times for semantic categories under these same instructions. On the other hand, the internal representations of semantic categories are theorized to contain more abstract conceptual information (Rosch, 1973, 1975a, b). This distinction can be viewed as a difference in the degree to which items within each of the two types of categories are related on a perceptual dimension, with members of color categories related primarily on the basis of perceptual similarity, while members of semantic categories are related primarily on a semantic or conceptual basis.

Some recent research suggests that semantic categories can be divided along a continuum into those categories containing members that are more visually homogeneous, hereafter called "perceptual" categories, and those which contain members judged to be more visually heterogeneous, hereafter referred to as "nonperceptual" categories (Sperber, *et al.,* 1982, 1984). One could argue that this distinction between perceptual and nonperceptual categories would also result in differences in the internal representations of such categories, with the representation of a perceptual category embodying more perceptual information, while that of a nonperceptual category embodys more abstract semantic or conceptual information.

The present experiment examined expected differences between perceptual and nonperceptual categories when pictures of category members where classified under physical identity instructions. It was expected that the facilitative effects of a category label prime on physically identical pairs would be obtained only for the perceptual categories, because of the hypothesized availability of visual features in the representation generated by the prime that could be used to facilitate the match. This is similar to the result that Rosch (1975b) found with color categories. No effect of priming would be expected for the nonperceptual categories due to the lack of visual information contained in the internal representation. In addition, response latencies to same-category pairs (pairs of members from the same category, which would be a "no" response) were expected to be slower for perceptual than for nonperceptual categories due to what Seymour (1976) has called pictorial confusability; that is, it was expected that the greater visual similarity between items in perceptual category pairs would make it more difficult for subjects to decide that these items were not physically identical compared to decisions on the same-category pairs for nonperceptual categories.

METHOD

Twenty adult, college-student volunteers, 8 males, and 12 females, made physical identity decisions (respond "yes," only if the two pictures are identical; respond "no" to all other picture pairs) on three types of picture pairs: physically identical (e.g., bus-bus), same-category (e.g., bus-motorcycle), and different-category (e.g., bus-apple). The stimuli consisted of photographic slides of pairs of pictures selected from eight semantic categories. Half of the categories had been judged to be perceptual categories (those categories in which members were judged to be perceptually homogeneous) and half to be nonperceptual categories (those in which the members were more visually heterogenous). The basis for such a distinction and the choice of particular categories were based on previous subjects' judged perceptions of visual similarity of category instances and on category-instance verification data (Sperber, *et al.,* 1984). Four instances were chosen from each of the eight categories selected for the present experiment. All instances were high typical exemplars of their respective categories, as rated in Rosch's (1975a) and Sperber, *et al.* (1984) typicality norms. The picture stimuli were color.photographed copies of pictures from the Basic Word Making Cards (Word Making Productions, Inc., P.O., Box 15038, Salt Lake City, Utah 84115).

Two separate stimuli lists were constructed, one from the perceptual category items, the other from the nonperceptual category items. Each list consisted of 64 physically identical, 32 same-category, and 32 different-category pairs. Half of the subjects made decisions on picture pairs from perceptual categories, such as insect and vehicle, while the remaining subjects made judgements on items from non-perceptual categories, such as sports equipment and furniture.

The apparatus consisted of a Kodak Carousel (Model C) slide projector equipped with a tachistoscopic lens, a voice-operated relay connected to a Hunter Model 120-C Klockounter for recording subjects' response latencies, and supportive programming equipment. The Klockounter was interfaced with the voice-operated relay and tachistoscopic lens such that the onset of the stimulus slide started the timing cycle and the subject's verbal response stopped the Klockounter.

Each subject was tested individually. Half of the subjects were presented with the perceptual category list and half with the nonperceptual category list. Subjects were instructed that they would be shown pairs of pictures and were to respond "yes" as rapidly as possible, if the two pictures were physically identical, and "no," if they were not (i.e., for same-category and different-category pairs). Half of the trials in each list were primed. Each primed trial began with the oral presentation of a category name (which was always a superordinate of at least one of the two pictures) followed approximately 2 seconds later by the presentation of the stimulus pair. For each unprimed trial, the procedure was the same except that the word "ready" was used instead of a category name. The subject was not informed of any possible relationship of the prime to the stimulus pair or of any

TABLE 1. Mean response times in msec.

	Picture Pair					
	Physically Identical		Same		Different	
Catory	Primed	Unprimed	Primed	Unprimed	Primed	Unprimed
Perceptual	643	670	708	680	673	676
	(66)[a]	(68)	(64)	(60)	(67)	(59)
Nonperceptual	625	623	637	630	642	645
	(51)	(55)	(60)	(63)	(57)	(60)

[a] Standard Deviations

possible benefit to be gained from the prime. There were approximately 10 seconds between each trial, at which time the subject's response latency to the preceding trial was recorded.

RESULTS

Mean response latencies for physically identical, same-category, and different-category trials were analyzed separately using a 2 x 2 analysis of variance. Category type was a between-subjects factor, while priming was a within-subjects factor. The mean response times for all conditions are presented in Table 1. Looking first at the results for the physically-identical pairs, primed stimuli ($\bar{x}$ = 634 msec) were responded to faster than unprimed stimuli ($\bar{x}$ = 646 msec; F = 12.97, df = 1,18, $P < .003$). This main effect of priming was, however, qualified by a significant Category Type × Prime interaction (F = 17.90, df = 1,18, $P < .001$). Additional analyses of this interaction revealed that a significant facilitation effect of the prime was found only for the perceptual categories (F = 28.14, df = 1,9, $P < .001$).

Turning next to the same-category pairs, significant main effects of Category Type (F = 4.89, df = 1,18, $P < .04$) and Priming (F = 17.84, df = 1,18, $P < .001$). were obtained. Perceptual categories were responded to significantly slower than nonperceptual categories ($\bar{x}$ = 694 msec and 634 msec, respectively). Primed stimuli were responded to significantly slower than unprimed stimuli ($\bar{x}$ = 673 msec and 655 msec, respectively). Both of these main effects were qualified by a significant Category Type x Prime interaction (F = 6.62, df = 1,18, $P < .02$). Analyses of this interaction revealed that the priming effect for the nonperceptual categories was not significant. However, for the perceptual categories, primed stimuli pairs were responded to significantly slower than unprimed pairs (F = 22.71, df = 1,9, $P < .002$).

No significant main effects or interactions were obtained for the different-category pairs.

DISCUSSION

The present experiment provided additional support for the utility of the distinction made between perceptual and nonperceptual categories and the corresponding differences in the availability of concrete visual information in the internal representation generated to a category prime. As predicted, a category label prime significantly aided physical identity decisions on physically identical pairs from perceptual categories, while it provided no help for decisions on pairs from nonperceptual categories.

Rosch (1975a, b) has argued that the internal representation that is formed from a category label prime of a semantic category does not provide perceptual or physical information that can be used in making decisions about physically identical pairs of members from that category. This is in contrast to the representations found with color categories under the same conditions, which do provide perceptual information that a subject can and does use to aid their decision making. The present experiment provides evidence that while Rosch's conclusion may be true for some semantic categories, it is not true for all semantic categories. Categories that have a high degree of visual similarity among their members behave much like Rosch's "perceptual" color categories; that is, the category label primes of perceptual categories in the present experiment did allow subjects to form an internal representation that contained sufficient perceptual or visual information to aid subjects decisions on physically identical pairs under the physical identity instructions. The internal representation formed from the prime of a perceptual category might serve to accentuate the visual features that instances of a perceptual category share in common. This accentuation allowed subjects to decide that the two stimuli in a pair were encoded. This was not the case for the nonperceptual semantic categories, in which evidence in accordance with Rosch's conclusions (1975a, b) was obtained. The internal representations of the nonperceptual categories in the present experiment apparently do not provide perceptual information that can be used, when making physical identity decisions on physically identical pairs, since no priming effect was obtained with pairs from these categories.

Another expected result from this experiment was derived from Seymour's concept of pictorial confusability. Seymour has suggested that the more the two pictures in a same-category pair are visually similar to one another, the more difficult it will be to decide that they are not physically identical and to give a "no" response. In the present experiment, it was predicted that the items in the same-category pairs of perceptual categories would be perceived as being more visually similar to one another resulting in the pictorial confusability suggested by Seymour. On the other hand, it was expected that no such effect would be found with the nonperceptual categories due to the relative lack of visual similarity within the same-category pairs. The results clearly supported the expected findings. The same-category pairs of perceptual categories were responded to significantly slower than the nonperceptual category pairs. A category prime presented before the stimulus pair had no effect on the nonperceptual categories, but it did significantly interfere with decisions on pairs from perceptual categories. The information made available by the internal representation formed to the prime of a perceptual category made it even more difficult for subjects to decide that the stimulus pair items were not physically identical.

The internal representation formed from the category label prime of a perceptual category apparently contains information that is not contained in the representation formed to the category prime of a nonperceptual category. As suggested earlier, this information is believed to involve the visual features that typical members of a perceptual category share in common. The internal representations formed with nonperceptual categories contain no information that affects either the postive decisions to physically identical pairs nor the negative decisions to same-category pairs. In conclusion, there appear to be differences in the internal representations of perceptual and nonperceptual semantic categories similar to the differences Rosch found between color and semantic categories. Such differences need to be recognized in future research involving semantic categories.

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SCIENCE EDUCATION

Chair: Vincent A. DiNoto, Jr.
Department of Physics
Jefferson Community College
1000 Community College Drive
Louisville, Kentucky 40272

Chair-Elect: Stanley S. Shimer
Science Teaching Center
Indiana State University
Terre Haute, Indiana 47809

ABSTRACTS

Using Video-Technology as an Aid to Classroom Observational Learning. Susan M. Bryant, Saint Mary's College, Department of Education, Notre Dame, IN 46556-5001.—The purpose of this presentation is to demonstrate the use of video technology as an aid to elementary school students' observation and study of ecology. A sixth grade class in an inner city environment discovered a nesting pair of mourning doves outside the schoolroom window. The teacher capitalized on the immediate interest of the students and developed instruction designed to 1) increase student understanding of the natural environment and of birds, in particular; 2) develop responsible attitudes toward wildlife; 3) teach observational and record-keeping skills; and 4) practice group problem-solving strategies. The edited video-tape and a student narrated slide presentation will show how the project evolved in the classroom and how teachers can take advantage of similar situations to promote learning with a high degree of student excitement and involvement.

Science Teaching with Bubbles. Mary L. French, Linton-Stockton Elementary School, Linton, IN 47441.—This session will let participants experience science teaching using bubbles. While enjoying the magical, "clean" fun of bubbles, the participants will incorporate the science process skills of observation, classification, measurement, prediction, inference, and communication. Explanations of how to reinforce graphing and charting skills using bubbles will also be offered in the presentation.

Teaching Tropical Ecology in the Tropics: The Possible Dream. David J. Hicks, Biology Department, Manchester College, North Manchester, IN 46962.—The tropical regions of the world contain valuable natural resources and are of great biological interest. It is of increasing importance that citizens, policy makers and biologists in the U.S. know about the tropics. The Central American country of Costa Rica is an excellent democracy which welcomes visitors from the U.S. Students of both basic and applied biology can find much of interest. The natural park system preserves samples of many natural ecosystem types. On the other hand, the pressures of a rapidly growing population provide examples of environmental and agricultural problems. Efficient logistic support for student groups can be provided by the Organization for Tropical Studies.

Instrumental Methods: Experiments for the High School Laboratory, An In-service Workshop for High School Teachers. Paul B. Kissinger, Physics and Astronomy Department, DePauw University, JOHN A. RICKETTS, Chemistry Department, DePauw University, and EUGENE P. SCHWARTZ, Chemistry Department, DePauw University, Greencastle, IN 46135.—Instrumentation for use in teaching the chemistry and physics laboratories is available in many high schools. However, in all too many instances, ineffective use of this instrumentation occurs. This workshop was designed to provide high school teachers of chemistry and/or physics a "hands on" experience with the instrumentation available in the high school. Fourteen participants performed laboratory experiments directly applicable in the high school laboratory. The workshop continued over five successive Saturdays from 10:00 a.m. to 3:00 p.m. The topics included in the program were: 1) Teaching Laboratory to Enhance Reasoning Abilities, 2) Wave Motion and Atomic Spectra, 3) Spectrophotometry, 4) pH, Its Meaning and Measurement, and 5) Lasers, A Tool for Understanding Wave Motion. The content of each of the sessions is described.

Mind Tester for Programmed Instruction. STANLEY S. SHIMER, Science Teaching Center, Indiana State University, Terre Haute, IN 47809.—Each participant in this session will learn how to make and use the mind-tester and programmed instruction cards. The mind-tester can be made by individual students in the classroom and utilized for individual drill and practice of various concepts and facts about different science topics. Participants will also be shown how their students can made packets of programmed instruction cards on the topics of their choice.

Pan Am Animal Sciences Exchange: Internationalizing Animal Sciences Education. MICHAEL H. STITSWORTH, Department of 4-H Youth, AGAD Room 228, Purdue University, W. Lafayette, IN 47907.—A $18,200 grant awarded to the Department of 4-H Youth at Purdue University by The National Association of the Partners of the Americans provided an exchange of Indiana 4-H club members and 4-S club youths in Rio Grande do Sul, Brazil. The Pan Am Animal Sciences Exchange permitted sending ten 4-H members enrolled in animal sciences 4-H project areas to Rio Grande do Sul for 6 week homestays during the summer of 1987. Purdue University faculty assisted the hosting Brazilian 4-S organization in structuring appropriate thematic experiences. The 4-H members lived on typical Brazilian animal production farms and toured agricultural training facilities, processing operations, and exporting facilities. In the summer of 1988, nine Brazilian 4-S club members lived on Indiana farms for six weeks to learn about animal science practices, research, and technology in Indiana. Four-H, a program of the Purdue University Cooperative Extension Service, is Indiana's largest non-formal educational program with a membership of 136,000 youth distributed among Indiana's 92 counties.

"HUMAN: A Comprehensive Physiological Model," a Content and Process Oriented Tool for Undergraduate Physiology Courses. ALBERT A. WILLIAMS, Manchester College, N. Manchester, IN 46962.—An important component of undergraduate physiology is an appreciation of the complexity of interactions which are involved in the homeostatic regulation of living systems. Compartmentalization of regulatory controls is an unrealistic simplification that is a disservice to the student. A second essential component of all science courses is the development of an appreciation of the difficulties involved in formulating a clear hypothesis, good experimental design, and the production of an "elegant record" that relates to the hypothesis and clearly demonstrates the effect(s) of a given stimulus on a physiological variable. The physiological simulation "HUMAN" serves both goals effectively. It is a computer simulation of physiological responses which computes over 200 physiological variables and allows the user to control more than 70 parameters. Both graphical and tabular versions are available. It has been effectively used in class lectures, as segment of structured laboratories, as a short assignment, and as the center of semester projects. It has served as a versatile tool that reinforces physiological concepts of homeostasis and the methodology of science.

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KARINOPTERIS, A FOSSIL PTERIDOSPERM FROM THE "PAPER" COAL OF INDIANA

Gary E. Dolph
Department of Botany
Indiana University Kokomo
Kokomo, Indiana 46904

Robert A. Gastaldo
Department of Geology
Auburn University
Auburn, Alabama 36849

William A. DiMichele
Department of Paleobiology
Smithsonian Institution
Washington, D.C. 20560

and

Diana M. Hunn
Department of Education
Indiana University Kokomo
Kokomo, Indiana 46902

INTRODUCTION

To many people, the concept that organisms evolve seems patently absurd. The opponents of evolution have argued 1) that morphologically distinct groups of organisms (created kinds) were independently created; 2) that genealogical descent and modification can be traced within created kinds (microevolution) but not between created kinds (macroevolution); and 3) that there are no known modern or fossil taxa that are morphologically intermediate between major groups. Their argument is that evolution is simply a belief and not an experimentally supported hypothesis (that is, a theory). If evolution is presented as a simple fact without giving the students concrete examples to work with, the students may have trouble deciding if the scientific viewpoint is correct. One method of supporting the study of evolution is to have your students work with real fossils in the laboratory. A number of suggestions will be offered in this paper that will allow you to develop a laboratory exercise for your students dealing with easily obtainable fossil plant remains from the Middle Pennsylvanian of Indiana. The laboratory exercise will not require extensive field work nor an extensive fossil collection.

Central to the laboratory exercise will be the maceration of an Indiana "paper" coal and the isolation of a Middle Pennsylvanian pteridosperm, *Karinopteris* sp., from it. During the Middle Pennsylvanian, two major groups of pteridosperms existed—the Medullosaceae and the Lyginopteridaceae (Stewart, 1983; Taylor, 1981). Members of the Medullosaceae generally have several vascular bundles in the stem (they are polystelic except for the genus *Quaestora*), have longitudinal

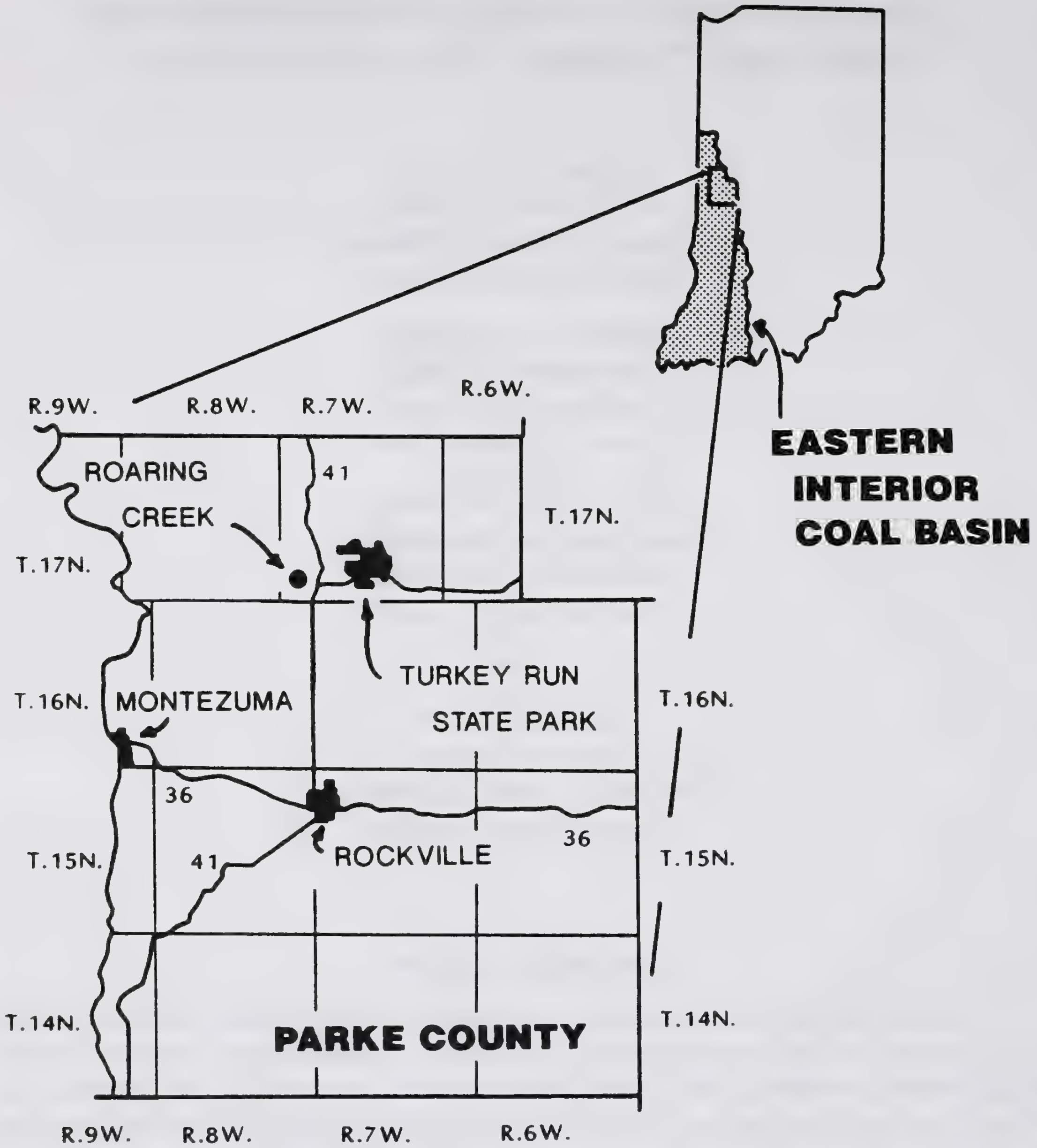

FIGURE 1. The location of Parke County and Roaring Creek in the Eastern Interior Coal Basin.

sclerotic bundles in the cortex, and have numerous traces scattered throughout the petiole. Members of the Lyginopteridaceae have a single vascular cylinder in the stem (they are monostelic), have transverse sclerotic bars in the cortex, and have one major petiolar trace after fusion. In both groups, the rachis (leaf axis) divides (bifurcates) into two major sections (a bipartite leaf). The presence of transverse sclerotic bars in the cortex indicates that *Karinopteris* has affinities with the Lyginopteridaceae, possibly to the structurally preserved *Schopfiastrum* (DiMichele, *et al.*, 1984).

A laboratory exercise based on *Karinopteris* will be unique in two ways. First, the pteridosperms (seed ferns) are completely extinct today. The last pteridosperms became extinct during the Permo-Triassic as lowland climates dried out approximately 225 million years ago. Second, although paper coals having different compositions and ages are known from Russia, Germany, France, and

Australia (DiMichele and Dolph, 1981), the paper coal of Indiana is the only reported coal of this type in the United States. As a result, your students will be working with an extinct group from a unique type of deposit.

PENNSYLVANIAN STRATIGRAPHY OF INDIANA

Rocks containing *Karinopteris* are found in west-central Indiana (Parke County) associated with coals along the eastern edge of the Eastern Interior Coal Basin (Figure 1). The Pennsylvanian rocks of the Eastern Interior Coal Basin in Indiana are confined to the following three Groups (Shaver, *et al.*, 1986):

1. McLeansboro Group (youngest Carboniferous)
    a. Mattoon Formation
    b. Bond Formation
    c. Patoka Formation
    d. Shelburn Formation
2. Carbondale Group
    a. Dugger Formation
    b. Petersburg Formation
    c. Linton Formation
3. Raccoon Creek Group (oldest Carboniferous)
    a. Staunton Formation
    b. Brazil Formation
    c. Mansfield Formation.

Although exposures yielding *Karinopteris* have been found throughout Parke County, Indiana, the specimens described in the literature and their geologic setting are best known from the valley of Roaring Creek. The paper coal at Roaring Creek comes from above coal C (the Upper Block Coal) in the Brazil Formation (Nelson, *et al.*, 1985). The most productive coals mined in Illinois and Indiana are found higher in the section in rocks of the Carbondale Group.

DEPOSITION AT ROARING CREEK

The exposed bedrock at Roaring Creek (7 1/2′ Wallace Quad., SW 1/4, Sec. 32, T 17N, R 7W) has been mapped by Nelson, Eggert, DiMichele, and Stecyk (1985; Figure 2). The following discussion of the deposition at Roaring Creek is taken largely from their account. The subsurface geology is currently being studied by the Indiana Geological Survey (Eggert, personal communication).

A major erosional surface (unconformity) exists in Indiana between rocks of the Mississippian and Pennsylvanian. Near the end of the Mississippian, the landscape changed gradually due to either uplift or a global sea level drop, followed by erosion of the surficial rock layers, in some places down to Devonian rocks. This created a deeply channelized surface (Bristol and Howard, 1971, 1974; Howard, 1979) in which stream aggredation occurred. Relief of up to 30 m was common on this erosional surface. Viewed from the northeast to the southwest, the Pennsylvanian topography changed from an upland to alluvial valleys and finally to a deltaic plain. Streams flowed across the area from the northeast to the southwest from a northeastern mountanous region.

A mixture of sandstones, siltstones, shales, coal, and "underclay" represent the Middle Pennsylvanian at Roaring Creek. Marine rocks have been found re-

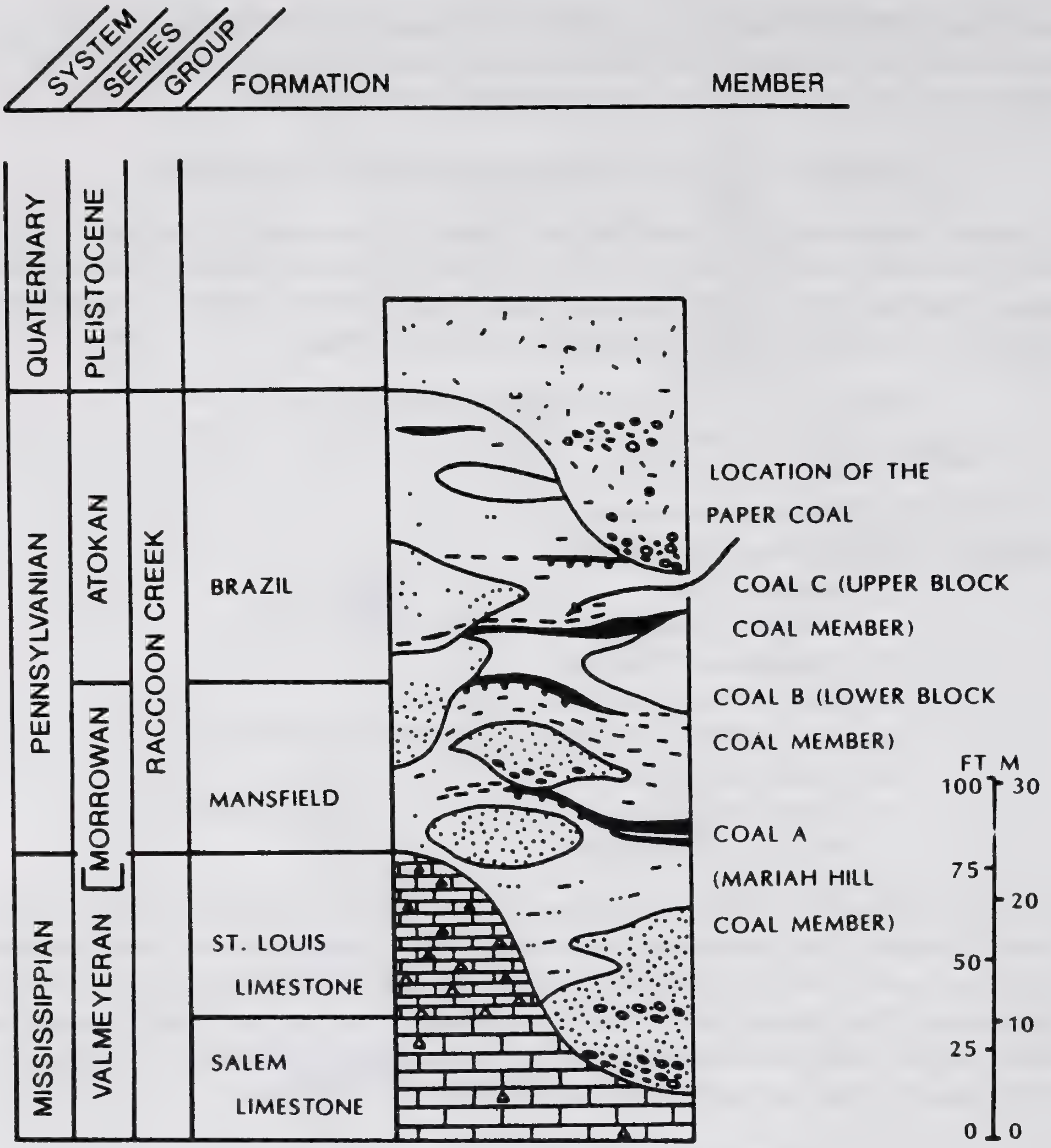

FIGURE 2. Generalized stratigraphic column from Roaring Creek (redrawn from Nelson, *et al.*, 1985).

cently (Kvale and Eggert, personal communication). The highly variable strata contrast sharply with the broad, level coal deposits formed by the younger migrating deltaic systems typical of the Middle Pennsylvanian (Carbondale Group) in much of Illinois and southwestern Indiana.

Several different depositional environments are encountered at Roaring Creek: 1) channels, 2) point bars, 3) natural levees, 4) crevasse splays, 5) floodplains (overbank deposits), and 6) swamps. In the channel sandstones, casts and coalified bark of driftwood logs are present. Crevasse splays surround upright trunks and stumps. Floodplain deposits are represented by gray shales containing numerous compression fossils. Claystone preserving rooting structures are common beneath the coal and represent ancient soils (paleosols). Alternating rooted mudstone (paleosols) and compression-containing gray shales indicate alternating periods of relative dryness and wetness.

At Roaring Creek, the swamp deposits are represented by coal seams that vary greatly throughout their extent. The three major seams are found throughout the area (Nelson, *et al.,* 1985). However, there may be some minor seams that are discontinuous. Swamps in this area of Indiana during the Middle Pennsylvanian were geographically restricted and short lived. They were subject to influxes of clastic material and erosion by stream channels. The floras are probably late Westphalian C in age, which places them in a wetter interval of the Pennsylvanian (Phillips and Peppers, 1984). Most coal seams formed on the delta plain or in coastal swamps further to the west. In Indiana, the coal seams formed along the extreme upper margin of the delta plain.

Three coals (coals A (Mariah Hill), B (Lower Block), and C (Upper Block); Figure 2) crop out in the valley of Roaring Creek and its tributaries. The ages of these coals were determined by biostratigraphic techniques based on miospore analysis (Peppers, 1979a, 1979b, 1982). The maximum thickness of coals A and B is about 0.9 m and the maximum thickness of coal C is about 0.6 m. The coal seams are not constant in elevation but may change elevation by as much as 9 m in a lateral distance of 30 m to 40 m. These differences probably resulted from a combination of differential compaction of the sediments before lithification, an irregular depositional surface in the area, and the activities of contemporaneous stream channels.

INDIANA PAPER COAL

Paper coal is found above coal C (Upper Block Coal equivalent) at some points along Roaring Creek. The texture and appearance of the paper coal will vary depending on the relative amounts of shale and cuticle present and on the amount of weathering that has occurred. Unweathered paper coal may vary from black to deep maroon in color. The clastic (shaley) component may form as much as fifty percent of the unweathered paper coal, giving it a distinct shaley cleavage. When the unweathered paper coal is split, large fragments of *Karinopteris* are visible along the bedding planes. At a weathered exposure, the papery texture will be obvious at the rock surface. Most of the clastic component will have weathered out, and the rock surface will feel like soft cloth. Cuticle exposed on the weathered surface may vary from deep brown to golden brown in color.

The paper coal consists primarily of the cuticle of the pteridosperm vine, *Karinopteris* (DiMichele, *et al.,* 1984). Previously, these cuticular fragments had been identified as *Sphenopteris bradfordii* (Neavel and Guennel, 1960) and *Eusphenopteris* (DiMichele and Dolph, 1981). When more specimens became available, their affinity with *Karinopteris* and not with *Sphenopteris* or *Eusphenopteris* became obvious.

Because cuticle is a biopolymer which is highly resistant to decay, it can be selectively concentrated in subaerially exposed plant litter (peat). The peat that lithified into coal C must have been exposed to the air at isolated sites within the original coal swamp. This exposure was responsible for the formation of the paper coal. The concentration of *Karinopteris* in the paper coal does not indicate that a monotonous stand of this pteridosperm covered the study area. *Karinopteris*, by virtue of having the thickest, most resistant cuticle of the plants in the area, was selectively concentrated during subaerial exposure of the peat. Cuticles of the other plants decayed on exposure.

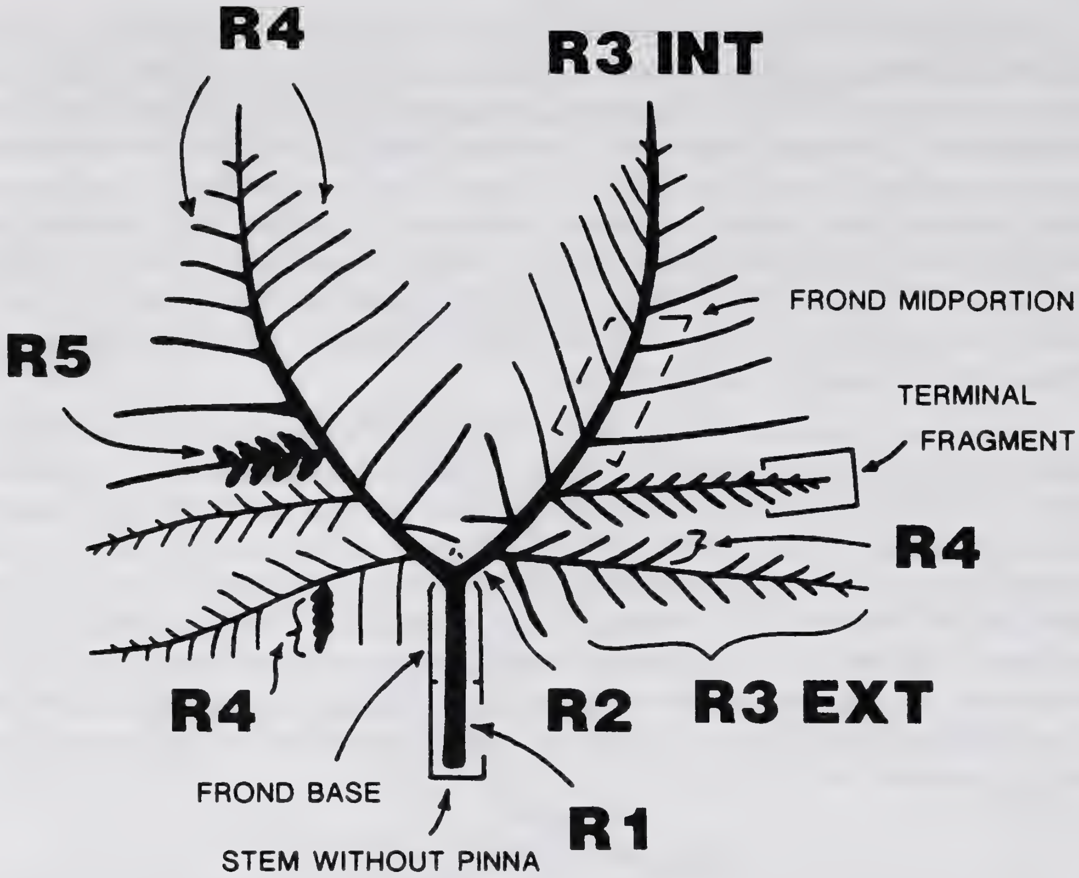

FIGURE 3. A stylized representation of the K-type frond of *Karinopteris* (redrawn from Gastaldo and Boersma, 1983a).

Nevertheless, the abundance of *Karinopteris* is unusual, because lycophytes (tree-sized relatives of modern club mosses) tended to dominate in the Euramerican peat-accumulating swamps of the Early and Middle Pennsylvanian. During the Middle Pennsylvanian in the Illinois Basin, lycophytes accounted for approximately three-fourths of the total peat volume (Phillips, Peppers, and DiMichele, 1985). Therefore, the flora from the paper coal at Roaring Creek has very little in common with typical Middle Pennsylvanian coal swamp floras found further to the west.

Other plant fossils are found in small numbers along with *Karinopteris* in the paper coal (DiMichele, *et al.*, 1984). These fossils include the lycophytes, *Lepidodendron aculeatum* and *Sigillaria brardii;* the sphenophytes (relatives of the modern scouring rush), *Calamites carinatus* and *Sphenophyllum* sp.; the pteridophyte, *Pecopteris miltonii;* the gymnosperms, *Alethopteris ambigua* (? *davreuxii*) and ? *Neuropteris obliqua;* and numerous small pteridosperm ovules. The fossil plant association supports the lithological conclusion that deposition was taking place along the coal-swamp margin. *Sigillaria* and *L. aculeatum* were characteristic of clastic, lowland areas and were rare in coal swamps. *Calamites* was most common in aggradational areas, probably along stream or lake margins (Oshurkova, 1977) and in parts of the swamp where peat was subaerially exposed (DiMichele, Phillips, and Peppers, 1985). *Alethopteris* and *Neuropteris* are foliage types characteristic of medullosan seed ferns. *Pecopteris* leaves are indicative of the presence of the marattialean tree ferns. Both the medullosan seed ferns and the marattialean tree ferns were most abundant and diverse in drier and microtopographically higher environments (clastic wetlands) than the coal swamps (Gastaldo, 1987).

A higher diversity flora is indicated by the results of spore and pollen (palynological) analysis of the coal associated with *Karinopteris*. Approximately 90 species of spores were recorded from the Roaring Creek coals (Peppers, 1979a, 1979b). The most abundant spores are associated with the arborescent lycophytes and marattialean tree ferns (DiMichele and Dolph, 1981). Because pollen and spores can be transported great distances in the air before deposition, they present a much broader picture of regional vegetational composition than the plants recovered from the paper coal.

PROCEDURE

The plant remains preserved in the Indiana paper coal consist almost entirely of the fragmentary cuticles of *Karinopteris*. Little cellular material remains except for transverse, sclerotic bars in the stems and rachises of *Karinopteris*. Although some specimens can be removed directly from a bedding plane without chemical treatment, the following steps should be followed when removing *Karinopteris* from the surrounding coal and shale matrix (DiMichele, *et al.*, 1984):

1. Immense the sample in 5% KOH until the cuticles separate. This may take several weeks depending on the amount of material being macerated. (You may have some difficulty deciding when to rinse your specimens (Step 2), because the KOH turns jet black when added to the paper coal.)
2. Rinse for 5 days in gently running water.
3. Place in 5-10% H_2O_2 (suproxal) for at least one hour. Superoxyl is purchased as a 32% solution. When added to the macerate, a highly exothermic reaction occurs. This reaction should be monitored carefully, especially if a higher strength solution is used. It is preferable to use a fume hood, rubber gloves, apron, and goggles, when handling superoxyl. The total time in superoxyl will vary depending on how weathered the material is.
4. Rinse in gently running water for 48 hours.
5. Remove the cuticles that have separated and place any aggregated material back into KOH.

These steps dissolve any vitrain (coaly material) present, disrupt the clastic (shaley material) matrix, and release the cuticle. Then:

6. Hand separate the cuticle under a dissecting microscope.
7. Dehydrate the cuticle using a graded alcohol series, suspend the cuticle in your mounting medium's solvent, and mount the cuticle onto glass slides of appropriate size. No staining is necessary. The alcohol dehydration should be carried out very slowly to prevent the material from becoming folded and brittle. As an alternative, the material can also be mounted in a water soluble mounting medium such as KARO.
8. Store the excess cuticle in a 1:1:1 mixture of distilled water, glycerol, and absolute alcohol (100% ETOH).

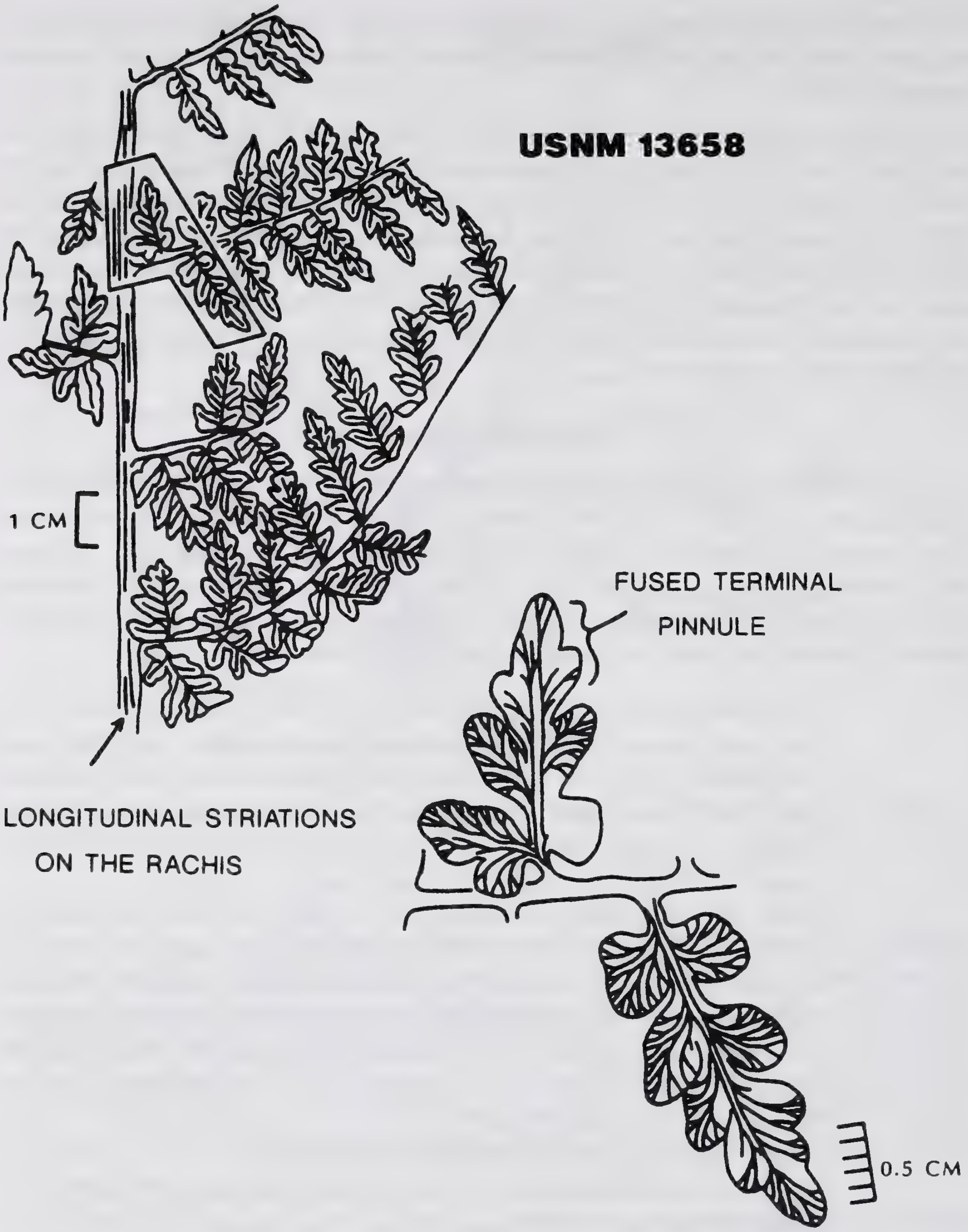

FIGURE 4. A line drawing showing a small portion of the frond of *Sphenopteris pottsvillea* (United States National Museum Specimen 13658).

K-TYPE LEAF ARCHITECTURE

A paper comparing the leaf architectures of two similar seed fern form genera, *Mariopteris* and *Karinopteris*, was published by Gastaldo and Boersma (1983a). A detailed discussion of *Mariopteris'* leaf architecture, their M-type frond (leaf), does not concern us here. However, an understanding of the leaf architecture of *Karinopteris*, their K-type frond (Figure 3), is very important to the following discussion. (The orders of karinopteroid rachial branching are normally placed in quotation marks to distinguish *Karinopteris* from *Mariopteris*. Because *Mariopteris* is not discussed in this paper, the quotation marks have been omitted.)

A primary rachis (R1) arises from the stem of the liana. Petiolar pinnules (pinnules located on the primary rachis (R1)) are not present as they are in some closely related form genera such as *Eusphenopteris* (Gastaldo, 1988). The primary rachis bifurcates (divides into two parts) to form two secondary rachises (R2). Each secondary rachis bifurcates after a short distance to form two tertiary rachises (R3). The inner tertiary rachises (R3 interior) are more strongly developed than the outer tertiary rachises (R3 exterior). Visually, the frond is divided into two distinct halves, each a mirror image of the other. Therefore, *Karinopteris* is bipartite. The tertiary rachises (R3) will bear laminate quaternary rachises (R4) and, in some cases, laminate quintuplicate rachises (R5). Each laminate rachis forms a pinna. In *Karinopteris*, each pinna bore sphenopteroid, lobate pinnules.

METHOD OF INTERPRETING *KARINOPTERIS* FROND FRAGMENTS

The most important reason for studying *Karinopteris* is that the students gain first hand experience in working with a fossil, the direct evidence of evolution. The experience may consist solely of removing material to make a single prepared slide (an approach best suited for elementary and middle schools) or it may involve reconstructing a typical frond based on the analysis of a wide range of material (an approach best suited for secondary schools and colleges). In the interest to time, some instructors might prefer to prepare the specimens themselves and only allow the students to reconstruct a typical frond.

The specimens of *Karinopteris* from the Indiana paper coals are quite fragmentary. Four types of material can be isolated (DiMichele, *et al.*, 1984): terminal frond segments, frond midportions, frond bases showing the bifurcating rachises, and stems and rachises without pinnae. These portions are blocked out on Figure 3 to allow for easy correlation between fragments and frond portions.

A comparison of the material with the reconstruction in Figure 3 should make it possible to identify the portions of the frond from which your specimens were derived. These placements can be made by determining the diameter of the largest axis of each fragment and then arranging the specimens from those having the smallest diameter to those having the largest diameter.

The terminal frond segments average about 1 mm in diameter (ranging from 0.3 mm to 2.0 mm in diameter). These terminal frond segments often can be identified by the presence of spine-like projections, which may have aided in supporting the liana in the upper level of the forest canopy (DiMichele, *et al.*, 1984). Fragments (1.5 mm to 5.6 mm in diameter) bearing lateral axes (ranchises between 1.1 mm to 2.0 mm in diameter) are from the center of the frond (frond midportions). Bifurcating rachises are rare. When found, the primary rachis averages 4.5 mm in diameter (ranging from 2.0 mm to 4.7 mm in diameter), and the secondary rachises above the bifurcation average 3.1 mm in diameter (ranging from 1.3 mm to 7.3 mm in diameter). Axes having transverse, sclerotic bars and lacking pinna may represent either the stem of the liana or the lower portion of a primary rachis. These fragments are normally between 0.75 cm and 2.0 cm in diameter. Unfortunately, if you rush your maceration, you can artificially strip a rachis of its lateral appendages, making its placement within the frond very difficult.

A study of *Karinopteris* points out the problems paleobotanists and paleontologists face when working with fragmentary fossil remains. Some fossils can be

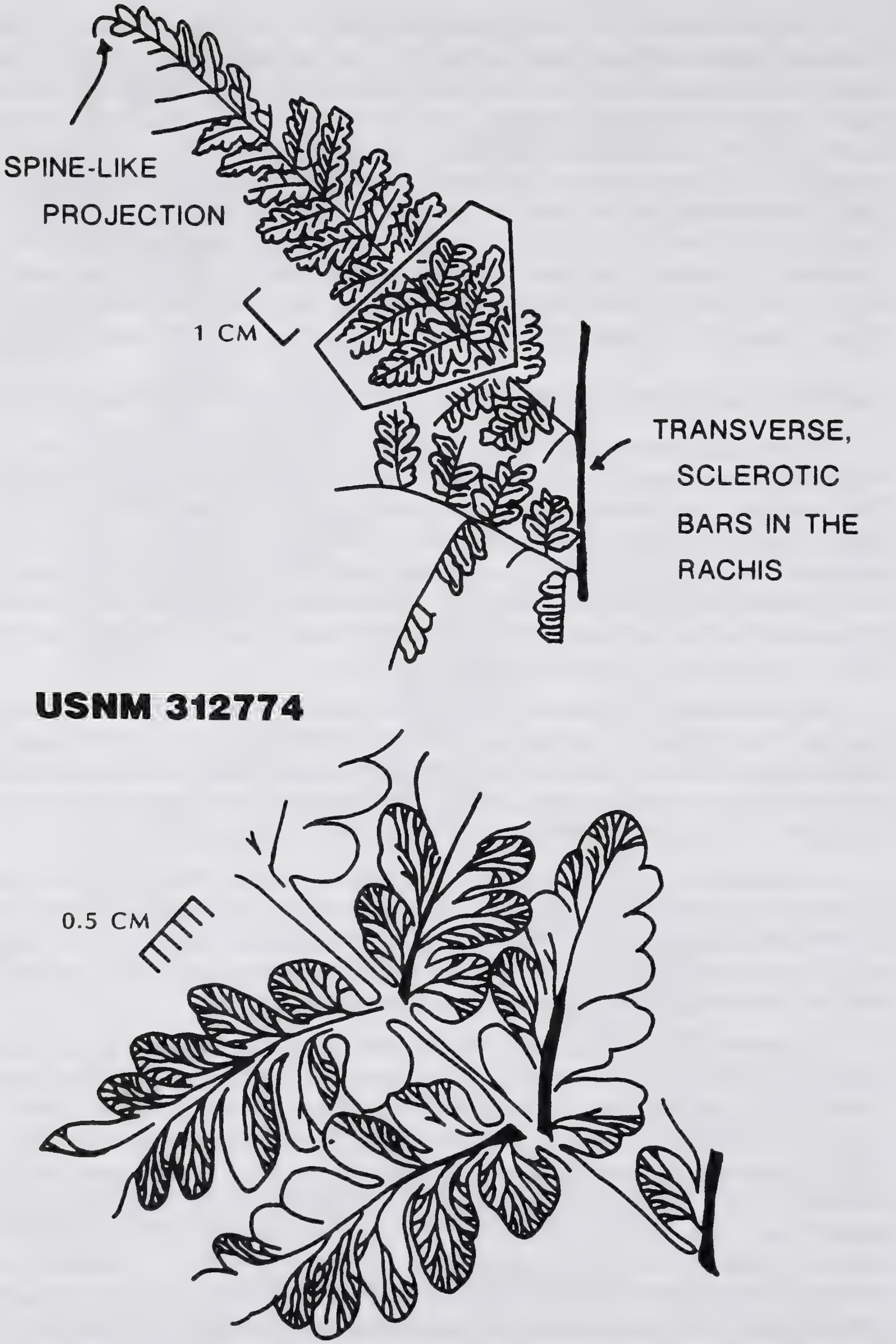

FIGURE 5. A line drawing showing a small portion of the frond of *Karinopteris soubeiranii* (United States National Museum Specimen 312774).

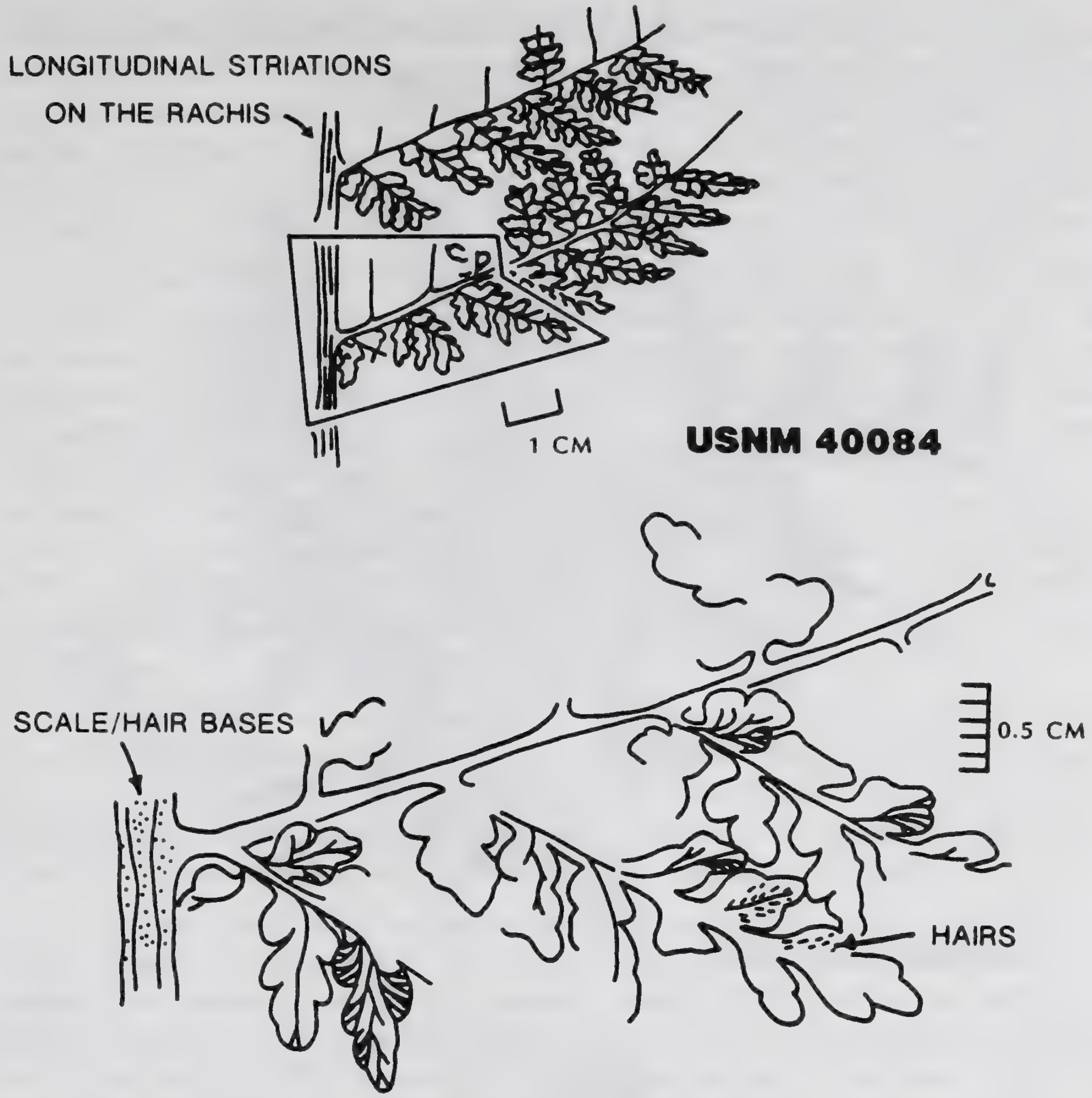

FIGURE 6. A line drawing showing a small portion of the frond of *Eusphenopteris paddocki* (United States National Museum Specimen 40084).

retrieved whole; for example, snail shells or pollen grains. Other fossils can be retrieved only in a very fragmentary state; for example, land plants and vertebrates. Only by carefully studying the specimens and developing methods for inferring position within the complete organism can the form of the original plant or animal be reconstructed.

A DICHOTOMOUS KEY

Most students are familiar with the traditional concept of the genus and species. When working with plant fossils, paleobotanists don't always know what the entire plant looked like. Pinnate fronds, such as those of *Karinopteris*, become fragmented (disarticulated) prior to burial and preservation. Rarely are large portions of fronds found intact (e.g., Gastaldo, 1988; White, 1943). Due to fragmentation, it is often difficult to match the separate parts of a frond with their true parent. Only when large specimens or large suites of specimens preserving various aspects of the parent are encountered can the many parts be placed together to form a complete frond. In order to classify the disarticulated parts

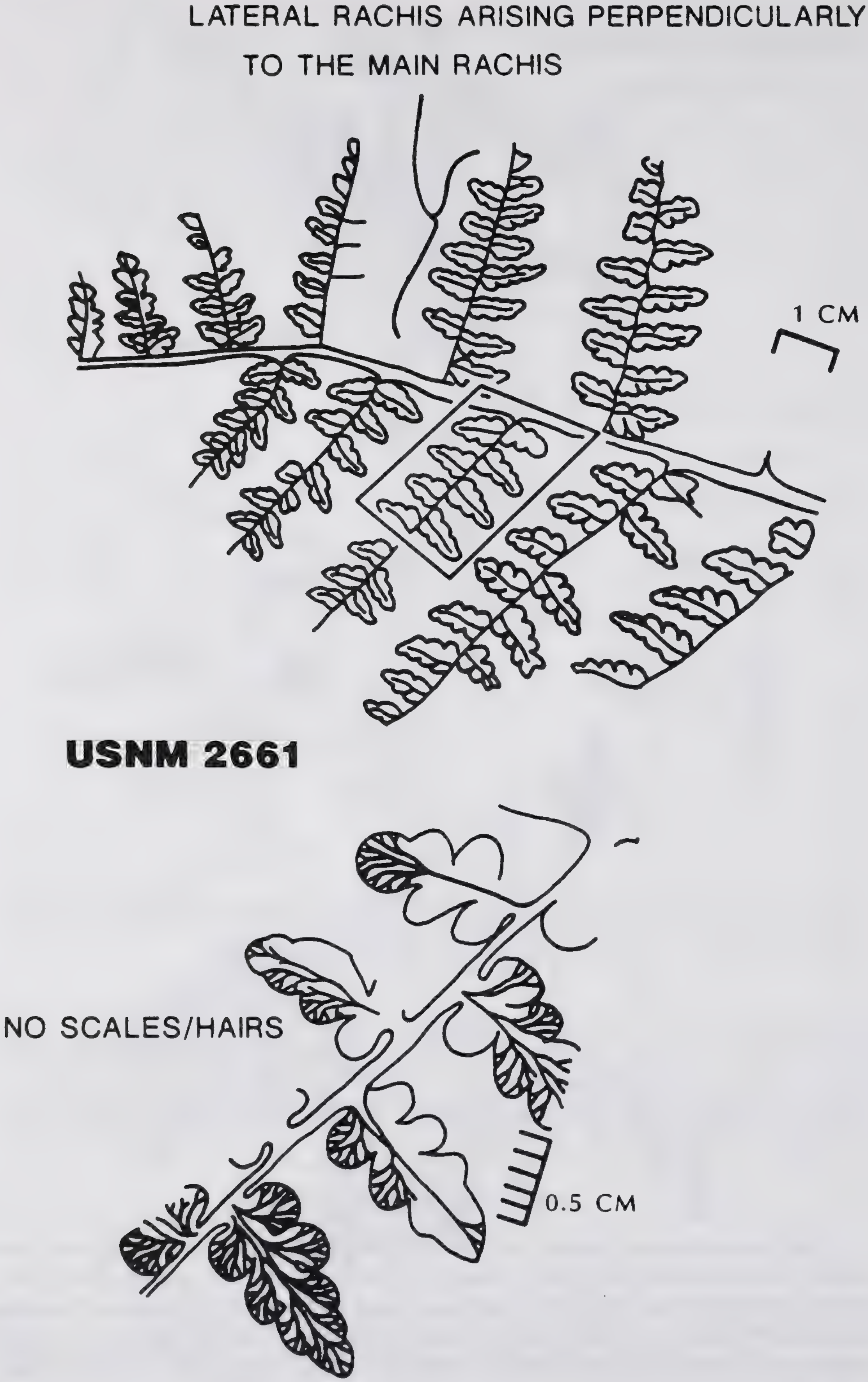

FIGURE 7. A line drawing showing a small portion of the frond of *Eusphenopteris lobata* (United States National Museum Specimen 2661).

unassignable to any known taxon, the International Rules of Botanical Nomenclature provides for a category called the form taxon. Form taxa may be used at any rank in the classificational hierarchy (e.g., a form family). *Karinopteris* is a form genus of pteridosperm foliage, and *K. soubeiranii* represents a specific type of karinopteroid foliage. The characteristics used to define the taxon are those that are most prevalent and shared by the parts that one wants to systematize.

In addition to preparing their own slides of *Karinopteris*, the students could construct a small dichotomous key for identifying the foliage of a number of pteridosperm species. Line drawings of *Sphenopteris pottsvillea* (White) Gastaldo & Boersma, *Karinopteris soubeiranii* (Zeiller) Boersma, *Eusphenopteris lobata* (White) Gastaldo & Boersma, and *E. paddocki* (White) Gastaldo & Boersma are provided. These species were originally part of the form genus *Mariopteris* as diagnosed or interpreted by White (1900, 1943), and their new assignments are based on a reexamination of White's specimens that was carried out by Gastaldo and Boersma (1983a, 1983b). The specimens illustrated are housed in the United States National Museum of Natural History (Smithsonian Institution, Washington, D.C.) and are real. None of the characteristics depicted are falsified.

Fragments of these species all share a number of similar characteristics (Figures 4-7). Within the major dichotomies of the rachis, the frond is bipinnate. At the tip, the pinnules are borne directly on the main rachis (R2). The pinnules alternate along the rachis and arise at an oblique angle. A single vein enters the pinnules and dichotomizes several times before reaching the pinnule margin.

The fronds also differ in a number of significant ways. In *Karinopteris soubeiranii* (Figure 5), the petiole and rachises are crossed by transverse bars. In addition, the pinnae near the tip of the main rachis (R2) as well as the rachis tip itself are elongated as spine-like projections. The axes of the remaining three species are longitudinally striated and lack the spine-like projections. In *Sphenopteris pottsvillea* (Figure 4), the terminal pinnule is fused with the subadjacent pinnules. In *Eusphenopteris paddocki* (Figure 6), scale/hair bases are present on the rachises. The pinnules of *E. paddocki* are all pubescent. Finally, *Eusphenopteris lobata* (Figure 7) differs from *E. paddocki* by having the lateral rachises inserted perpendicularly on the side of the main rachis toward the frond apex. There is no evidence for scale/hair bases on *E. lobata*.

Based on these differences, any number of dichotomous keys, such as the two given below, can be developed:

1. Rachis crossed by transverse bars; terminal pinnules end in spine-like projections .... *Karinopteris soubeiranii*
1. Rachis longitudinally striated; spine-like projections lacking 2

2. Terminal pinnule fused to subadjacent pinnules .... *Sphenopteris pottsvillea*
2. Terminal pinnule free 3

3. Scale/hair bases present on rachis; pinnules pubescent .... *Eusphenopteris paddocki*
3. Scale/hair bases absent; not pubescent .... *E. lobata*

or

1. Scale/hair bases present on rachis;
pinnules pubescent .... *Eusphenopteris paddocki*
1. Scale/hair bases absent; not pubescent 2

2. Rachis crossed by transverse bars; terminal pinnules end in
spine-like projections............................ *Karinopteris soubeiranii*
2. Rachis longitudinally striated; spine-like projections lacking............ 3

3. Terminal pinnule fused to subadjacent
pinnules ....*Sphenopteris pottsvillea*
3. Terminal pinnule not fused to subadjacent
pinnules .... *Eusphenopteris lobata*

The specimens of *Karinopteris* found in Indiana have not been assigned to an individual species (DiMichele, *et al.,* 1984). The above keys can be modified to identify the Indiana specimens by replacing *Karinopteris soubeiranii* with *Karinopteris* sp.

OUTCOMES

A number of valuable student outcomes can result from working with specimens of *Karinopteris*:

1. This experiment will allow the students to replicate studies of the reconstruction of *Karinopteris*. Their work will show that scientific inquiry is repeatable. The original author's hypothesis, the nature of the bipartite frond and its architecture, can be tested and retested with the same or nearly the same results.

2. The students will see that evolutionary theory has a strong empirical basis. Evolution is not an idea or a belief. It is a viable working hypothesis that is supported by an abundance of actual fossilized specimens of ancient life forms.

3. The rules of biological nomenclature can be discussed and the concept of form taxa can be introduced. Paleobotanists have a tendency to emphasize disarticulation and to give separate names (form taxa) to each disarticulated part. In comparison, disarticulation has not been enshrined by the vertebrate paleontologists. They have no form taxa. Should a tooth and femur, previously standing as two distinct taxa, be found to go together, they are placed in the same taxon. The principle of priority is applied, and they are given one name. This practice had not been followed in paleobotany Students should be made aware of the advantages and distadvantages of each approach.

4. The development and function of a taxonomic key can be introduced or reinforced.

5. Leaf architecture (frond morphology) and terminology can be studied. A knowledge of the appropriate terminology will provide the students with one of the tools necessary to test the hypothesis that the leaves of *Karinopteris* are constructed in a bipartite pattern.

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SOIL AND ATMOSPHERIC SCIENCES

Chair: Ronald W. Przybylinski
National Weather Service
Indianapolis International Airport
Box 51526
Indianapolis, Indiana 46251

Chair-Elect: C.W. Lovell
Department of Civil Engineering
Purdue University
West Lafayette, Indiana 47907

ABSTRACTS

A Comparison of MOS Values to Observed Readings on Clear Calm Nights with Varying Snow Depths. Timothy W. McClung, National Weather Service, NOAA, Michiana Regional Airport, South Bend, IN 46628.—Forecasting low temperatures on clear calm nights in the summer usually is routine, but in winter, especially with a significant snow depth, it can be quite challenging. A varying number of cases, totalling ninety-five, from twenty-three different cities in 1986 and 1988 are used to determine how accurate MOS forecasts are in predicting nighttime lows over snow covered ground when skies are clear and winds are calm. In forecasts when less than one inch of snow was on the ground, guidance was fairly accurate. However, a slight cold bias was noted. When snow depths ranged from one to five inches, MOS forecasted lows were erratic. However, average results over the whole category have shown that MOS deviated from the actual low by only one-tenth of a degree. When locations were covered by six or more inches of snow, MOS guidance was very poor. In the ninety-five cases examined, MOS had an average warm bias of 7.3 degrees.

Performance of the AFOS Data Analysis Program (ADAP) over the Lower Great Lakes Region During the 1988 Spring and Summer Convective Seasons. R. W. Przybylinski, National Weather Service, NOAA, Indianapolis Int'l Airport, Indianapolis, IN 46241.—During the early spring of 1988, a new application program called AFOS Data Analysis Program (ADAP) was installed at WSFO Indianapolis. The ADAP program is executed hourly and generates a host of surface based kinematic fields. Several severe and non-severe convective cases during the spring and summer of 1988 have been collected and examined to determine the strengths and weaknesses of several ADAP parameters. Preliminary findings have shown that once several fields become in phase with each other (i.e., strong warm advection superimposed over the surface moisture convergence axis and/or the strongest instability axis superimposed over the weakest part of the capping inversion when less than two degrees) significant or severe convective activity often occurred. Additional preliminary findings have shown that: (1) severe convection often occurred within the gradient region of the strong instability axis and where surface based lifted index values exceeded −10; and (2) significant or severe convection usually propagated along the moist side of the surface moisture convergence axis. Several cases will be presented to show these findings.

A Look at Maximum Temperature Bias in MOS on a Monthly and a Seasonal Basis. DAVID R. TUCEK, National Weather Service NOAA, Michiana Regional Airport, South Bend, In 46228.—Model Output Statistics (MOS) maximum temperature data for South Bend was analyzed to determine the frequency and magnitude of temperature bias for warming and cooling events. Results were tabulated on a monthly and seasonal basis. Overall, MOS correctly forecast the direction of maximum temperature change from one day to the next around 80% of the time. During autumn and winter, MOS exhibited a warm bias for warming and cooling events. During spring and summer, MOS had a warm bias for cooling events and a cold bias for warming events. The months within transition seasons appeared to be the most reliable predictors of bias. Summer was the least reliable trend predictor except for the drought summer of 1988 (June and July only) which consistently under-forecast warm-ups and overforecast cool-downs. Average absolute errors for the seasons ranged from 2.6 to 3.6 degrees; summer and the months of summer averaged lowest. For all seasons, errors tabulated most frequently ranged from one to three degrees. The range of errors was largest in autumn, the month of November in particular.

Temperature Anomalies During the Drought of 1988. THOMAS B. WILLIAMS and SHERMAN R. SHEWMAKER, Department of Geography, Indiana University—Purdue University at Indianapolis, Indianapolis, IN 46202.—A recurrent weather pattern of clear skies, dry air, and minimal rainfall prevailed during early summer 1988, causing a widespread drought and producing unusually large daily ranges of temperature. Daytime high temperatures rose much above normal while overnight lows dropped below normal as the unchanging weather conditions allowed both rapid heating during the day and rapid radiational cooling at night. From May through the first 10 days of July, daily temperature ranges averaged more than 28.0°F. The most important factors controlling diurnal temperature range are cloud cover and atmospheric moisture content. Early summer was characterized by an absence of clouds, limited supply of moisture (indicated by low dew points), and lack of significant rainfall. Between April 23 and July 9, rainfall totaled only 1.53 inches, 15.9% of the normal amount expected through the period. In comparison to prior years and to climatic normals, weather conditions in May, June, and early July 1988 were clearly abnormal, and represent a distinct anomaly in the climate record.

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IS OUR INDIANA CLIMATE WARMING?

Robert F. Dale
Agronomy Department
Purdue University
West Lafayette, Indiana 47907

INTRODUCTION

This summer's severe drought spawned many news media accounts (e.g., *Newsweek*, July 11, 1988, and *Fortune*, July 4, 1988) of "record climatic warmth in the 1980s", and there were suggestions that this warming may be caused by an enhanced greenhouse effect. Note that the author has added the word "enhanced" to the greenhouse effect, because the media accounts led readers into believing that the atmospheric greenhouse effect was bad. On the contrary, it is what makes the earth habitable by reducing the temperature extremes from those which would occur without a protective atmosphere, such as the extremes which occur on the moon.

In introductory meteorology, the student is taught that the three major atmospheric greenhouse gases are carbon dioxide (CO_2), ozone (O_3), and water vapor (H_2O). The media have written about the increasing CO_2, chlorofluorocarbons, methane, and other trace gases but have ignored the most important variable greenhouse gas, water vapor. Briefly, these atmospheric gases allow the solar, or short wave, radiation to pass through the atmosphere with little absorption, but they absorb and reradiate the returning earth, or longwave, radiation. Thus, in the radiation balance, the atmosphere acts as if it were the glass on a greenhouse. There is no doubt that CO_2 and the other dry greenhouse gases are increasing, except possibly for O_3. Thus, it seems logical that as the greenhouse gases increase, the earth's air temperature should also increase. The atmosphere is a complex physical system, however, and temperatures over a portion of the northern hemisphere are not necessarily a reflection of the hemispheric radiation balance.

Reports on climatic warming have been based on two information sources: first, on estimates of historical, or current, climatic warming; and second, on projections of warming into the 21st century, using climatic models in which usually a doubling of the CO_2 content of the atmosphere has been assumed. In this paper, only the first information source will be discussed—historical temperature trends—recognizing that observed climatic trends are nearly always a mixture of large-scale natural and anthropogenic climatic effects and of local environmental effects (Lowry, 1977).

The principle media sources for the global warming have been Hansen and Lebedeff (1987), who reported the global annual mean temperature had increased + 0.5 to 0.7 deg C in the past century, and Jones, *et al.* (1986; Jones, 1988), who found the Northern Hemisphere annual mean temperature was 0.4 deg C warmer in the 1921-84 period than in the 1851-1920 period. Although the data base in these and other temperature trend studies is derived primarily from the Smithsonian, U.S. Weather Bureau, and U.S. Department of Commerce World Weather Records (WWR), slight differences occur in their temperature trend analyses. The

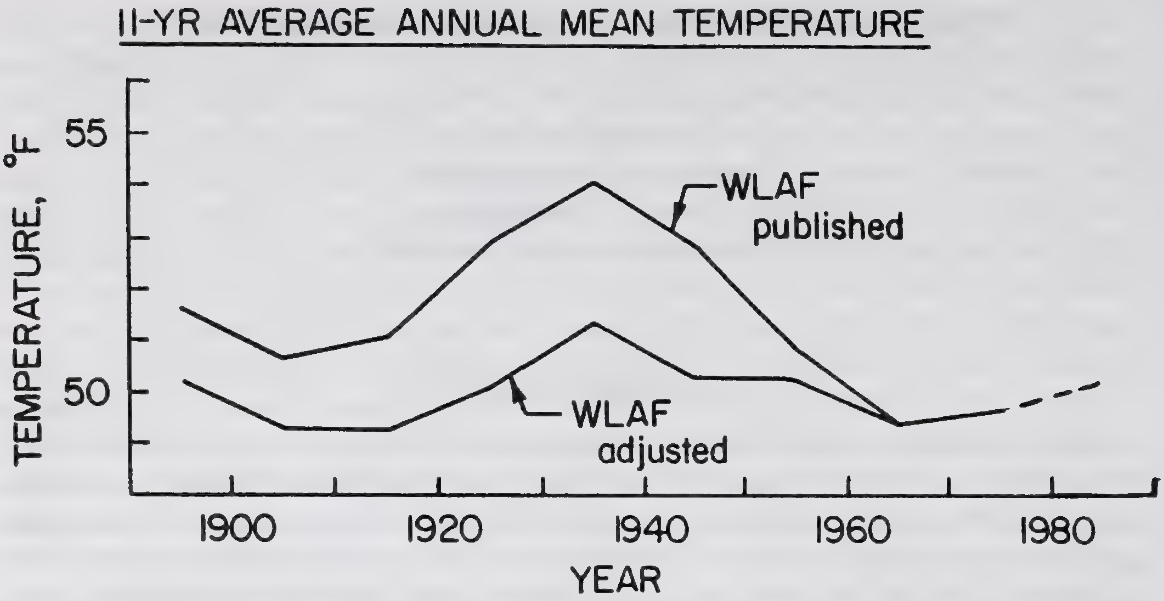

FIGURE 1. Mean annual temperature for indicated decade (11-yr average plotted at middle year), 1890-1990, adjusted to present location of West Lafayette 6NW Indiana (from Epperson and Dale, 1984).

differences result from different interpolation methods, reference periods, and considerations of "non-climatic" trends caused by changes in the observational network or the local environment. For example, an important bias in a hemispheric or global air temperature trend is caused by the growth of cities and attendant heat sources around most of the long-record WWR stations, producing what is commonly called the urban heat island effect (Landsberg, 1981; Kukla, *et al.* 1986). The WWR stations used to obtain a temperature average for a grid point in the Indiana area would be Cairo IL, Chicago IL, Cincinnati OH, Columbus OH, Madison WI, Nashville TN, St. Louis MO, Urbana IL, and Wooster OH. All of these cities have grown rapidly. These urban-influenced temperature records are carried into the grid point averages, which are used for determining the hemispheric and global temperature averages. Hansen and Lebedeff (1987) and Jones, *et al.* (1986) recognized this problem and tried to adjust for the urban effect. Karl and Jones (1989), using an enhanced U.S. Historical Climate Network (HCN), estimated the urban temperature bias in area-averaged surface air temperatures in the United States. They concluded that in the period 1901-1984 the urban-caused bias (+ 0.1 to 0.4 deg C) was larger than the overall U.S. temperature trend for the same period (+ 0.16 deg C/84 years). Unfortunately, there has not been a similar study of the effect of the urban bias in the hemispheric or global average temperature trends.

Rather than attempt to evaluate the urban temperature bias for all of the global weather stations, as Karl and Jones did for the U.S., the annual mean temperature from single homogeneous rural climatological stations in the middle to high latitudes can be used to monitor Northern Hemispheric warming (just as the Mauna Loa Observatory (CDIAC, 1988) has been used to monitor CO_2). There will be greater year-to-year variability in the annual mean temperatures from a single station than for the Northern Hemispheric temperature means, because regional anomalies tend to average out over the Northern Hemisphere. Jones

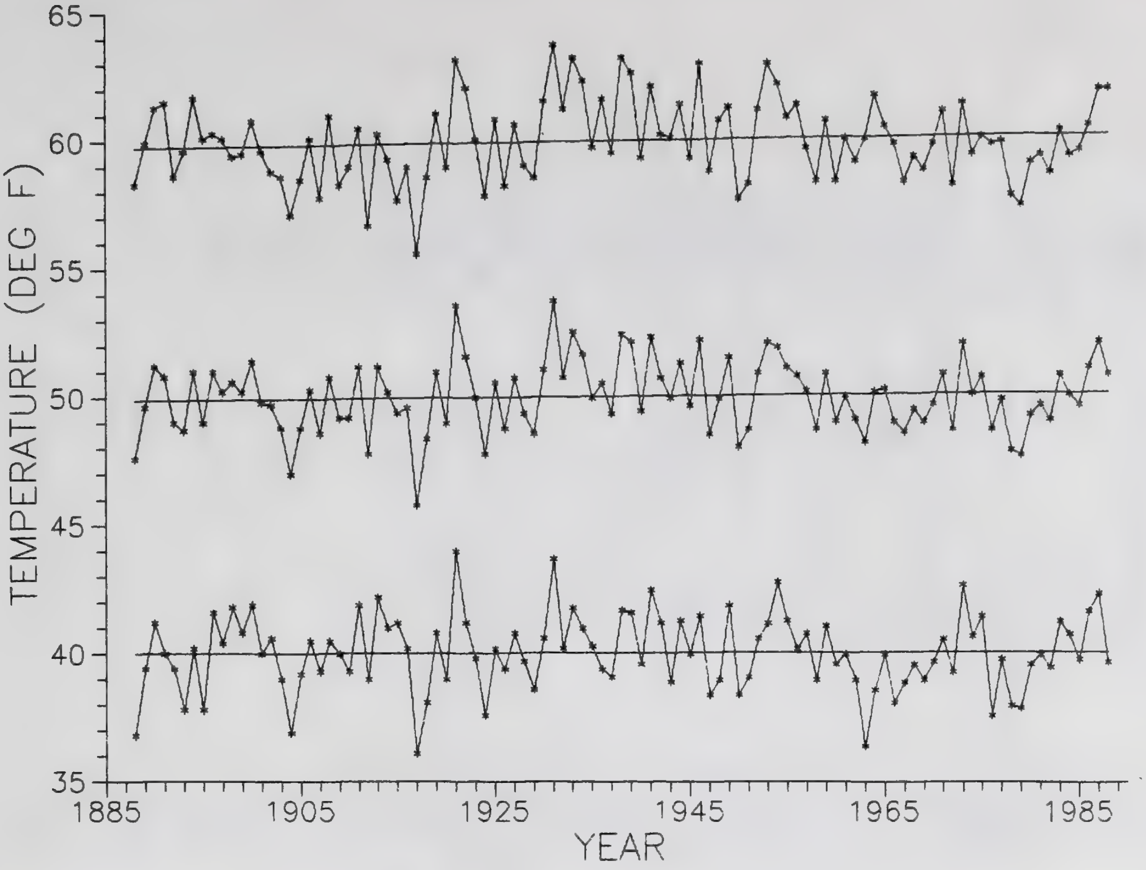

FIGURE 2. Annual mean daily maximum, mean, and mean daily minimum air temperatures for indicated year, 1888-1988, adjusted to present location of West Lafayette 6NW Indiana. Linear time trend for annual mean daily maximum + 0.007 deg F/yr (r = 0.13), for mean + 0.004 deg F/yr (r = 0.08), and for mean daily minimum = 0.001 deg F/yr (r = 0.02).

(1988, Figure 2) charted regions of cooling and warming in the Northern Hemisphere during the 1967-1986 period, but any long-term trend in natural climatic warming should be reflected in a time series of annual mean air temperatures from a rural climatological station, i.e., averages of 365 daily maximum and 365 daily minimum temperatures for each year.

Few, if any, long record climatological stations have been in the same location with an unchanging local environment. Consequently, the time series of temperatures reflects not only the climatic variability but also the nonclimatic variability and trends. Since the fifties, short term operational weather and hydrologic forecasting needs, with moves toward automation of observations, have had priority over maintenance of homogeneous climatic networks. Consequently, climatologists must make sense of an increasingly heterogeneous climatological base. For example, just by changing the time of a once-daily climatological observation (at Indianapolis) from 1900 EST to 0700 EST, the January mean air temperature would be decreased 2.6 deg F (Schaal and Dale, 1977). Nelson, *et al.* (1979) showed that a sufficient number of stations had experienced this time of observation change (PM to AM for operational reasons) to create a "non-climatic" cooling of Indiana summers of about 0.8 deg F from 1949 to 1979. In the U.S., where cooperative observers are relied on more than in other areas of the world, the time of observation bias tends to offset the urban warming bias.

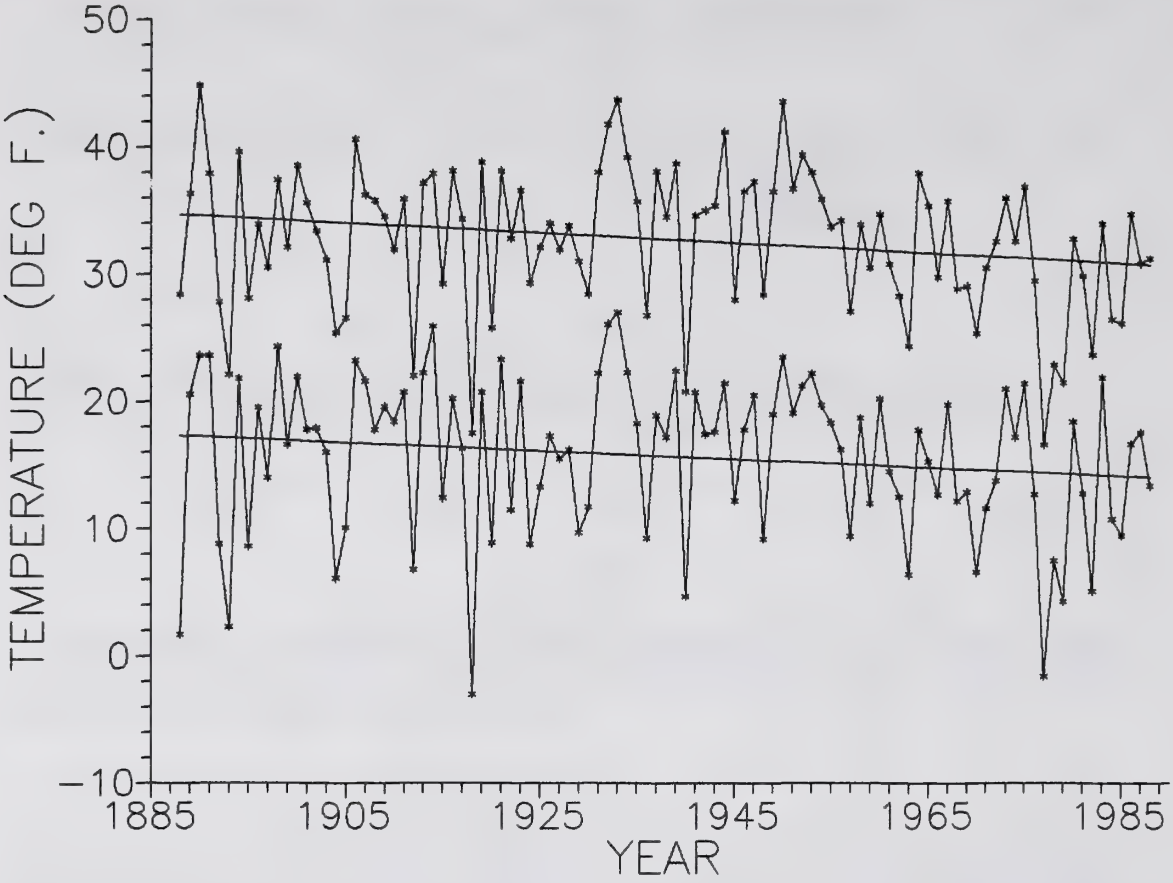

FIGURE 3. January mean daily maximum and mean daily minimum temperatures for indicated year, 1888-1988, adjusted to present location of West Lafayette 6NW Indiana. Linear time trend for mean daily maximum − 0.04 deg F/y (r = − 0.20*) and for mean daily minimum − 0.03 deg F/yr (r = − 0.15). * Significant at 0.05 level.

The WWR data base used in the climatic warming literature has only monthly and annual mean temperatures. The enhanced HCN data base used by Karl and Jones has monthly mean daily maximum and mean daily minimum temperatures. However, they did not use them in their analysis. Since there is no short wave radiation at night, the minimum temperature is almost exclusively controlled by the longwave radiation budget. Thus, one might expect that an enhanced greenhouse effect would be more evident in the mean daily minimum than in the mean daily maximum or in the mean temperatures. Therefore, the mean daily temperature range (mean daily maximum – mean daily minimum) should decrease, if there were an enhanced greenhouse effect.

In this paper, mean daily minimum, mean, and mean daily maximum temperature data from a rural climatological station in northern Indiana were adjusted for non-climatic biases from 1888 through 1988 and then examined for trend for evidence of climatic warming. In addition, the mean daily temperature range was examined for downward trend as evidence of an enhanced greenhouse effect.

MATERIALS AND METHODS

The data used were the mean daily maximum and mean daily minimum temperatures for January, for July, for the whole summer (June-August), and for

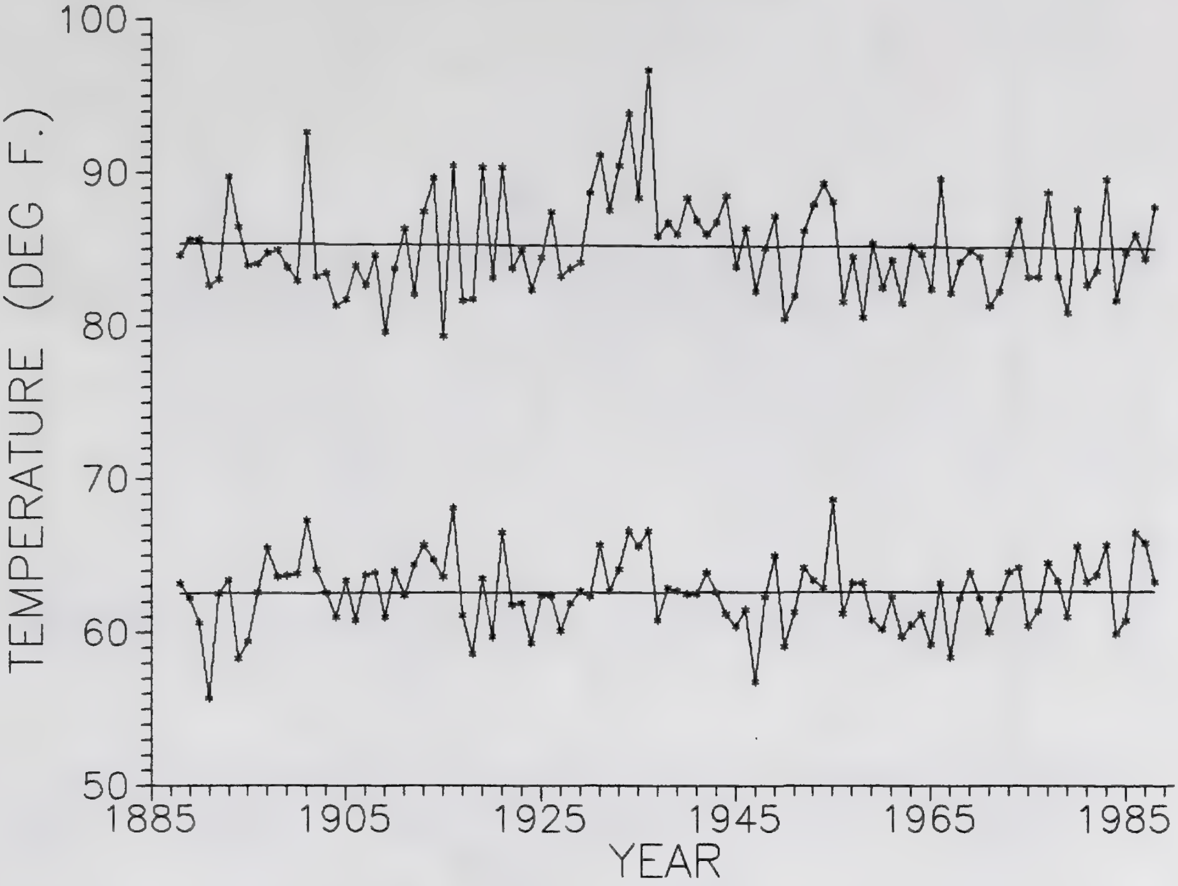

FIGURE 4. July mean daily maximum and mean daily minimum temperatures for indicated year, 1888-1988, adjusted to present location of West Lafayette 6NW Indiana. Linear time trend for mean daily maximum − 0.004 deg F/yr (r = −0.03) and for mean daily minimum + 0.001 deg F/yr (r = 0.01).

the year from West Lafayette 6NW, Indiana at 40 deg 28 min N, 87 deg 00 min W (U.S. Weather Bureau and U.S. Department of Commerce, NOAA, 1888-1988). The West Lafayette 6NW climatological station (# 9430) now has an ideal rural location at the Purdue University Agronomy Farm, about 10 km northwest of West Lafayette. Climatological observations are taken at 0800 EST with temperatures from standard liquid-in-glass thermometers exposed in a Cotton-Region Shelter. The station locations before 1954, however, were not always ideal. Using a series of overlapping observations from Whitestown, 80 km southeast of West Lafayette and one of the best reference climatological stations in Indiana since 1909, Epperson and Dale (1984) developed non-climatic temperature bias estimates to be applied to monthly annual mean daily maximum and mean daily minimum temperatures from each of the earlier locations to adjust the temperatures recorded during the respective location period to those for the present rural location. For example, from July 1, 1917 to January 31, 1949 the thermometer shelter for the West Lafayette climatological station (# 9427) was located on the roof of the Purdue University Agricultural Administration Building with observations taken at 2000 EST. During this period, the annual mean daily maximum temperatures were reduced 2.4 deg F and the annual mean daily minimums 3.2 deg F (2.8 for mean) to be equivalent to those recorded at the present rural location of West Lafayette 6NW. In like manner, the mean daily maximum and minimum temperatures for other periods were adjusted to create the climatological series

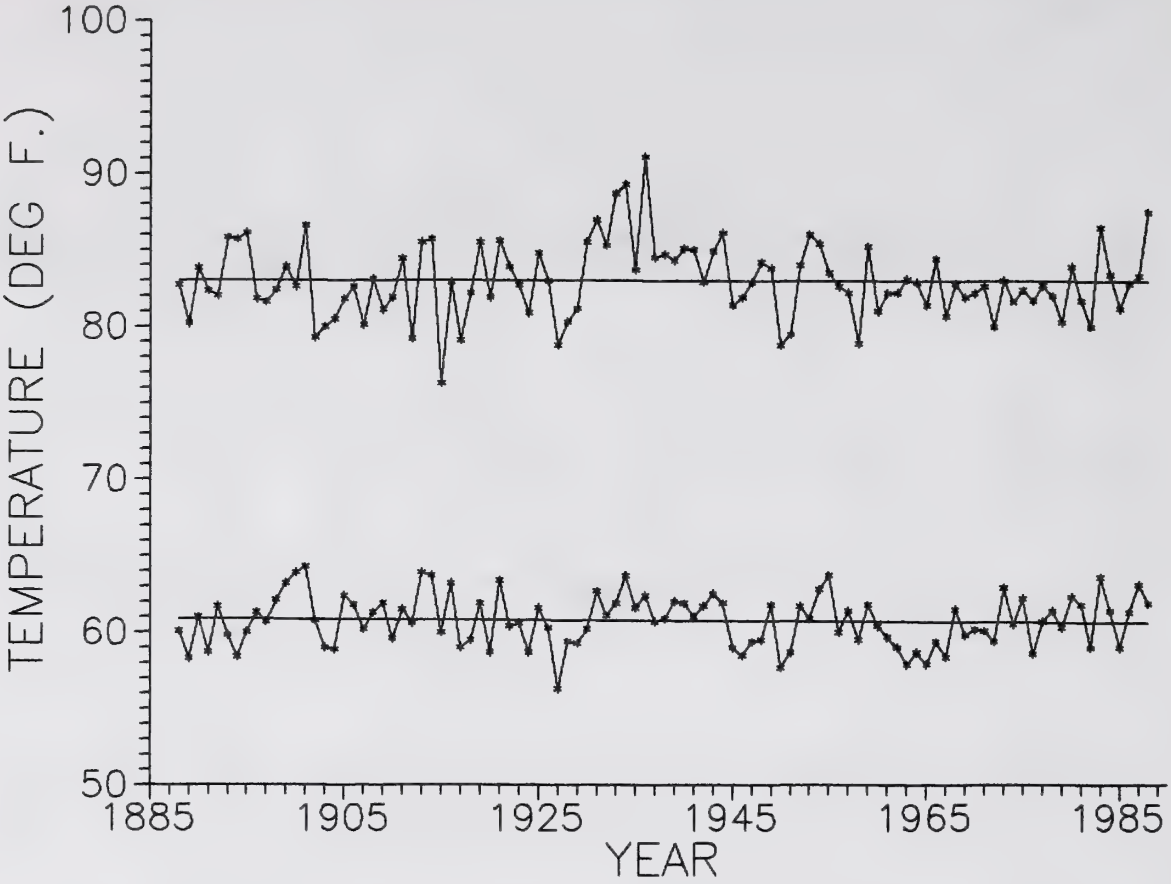

FIGURE 5. Summer (June-August) mean daily maximum and mean daily minimum temperatures for indicated year, 1888-1988, adjusted to present location of West Lafayette 6NW Indiana. Linear time trend for mean daily maximum − 0.0006 deg F/yr (r = − 0.007) and for mean daily minimum − 0.003 deg F/yr (r = − 0.04).

used in this paper. For comparison, the decadal (11-year) adjusted annual means, as well as those from the published (unadjusted) record (U.S. Weather Bureau and NOAA, 1888-1988), are reproduced from Epperson and Dale (1984, Figure 5) in Figure 1.

In addition, the mean daily air temperature ranges (mean daily maximum − mean daily minimum) were calculated and plotted by year for each of the January, July, summer, and annual periods. Finally, linear time trends for each of the temperature variables were fitted by least squares regression on year for the 101-year records.

RESULTS AND DISCUSSION

The mean decadal temperatures plotted in Figure 1 were extended through 1985 (representing the 1980-1990 mean) by using the 1960-1988 means for the 1989 and 1990 annual means. Although there is an upward temperature trend from 1960 through 1990, it is not as great as that from 1910 to 1940, the adjusted annual mean temperatures for the 1930-1940 period averaging 51.7 deg F, compared to the preliminary 1980-1990 11-year mean of 50.2 deg F.

The annual mean daily maximum, mean, and mean daily minimum temperatures for 1888 through 1988 (using November and December 1960-1987 means

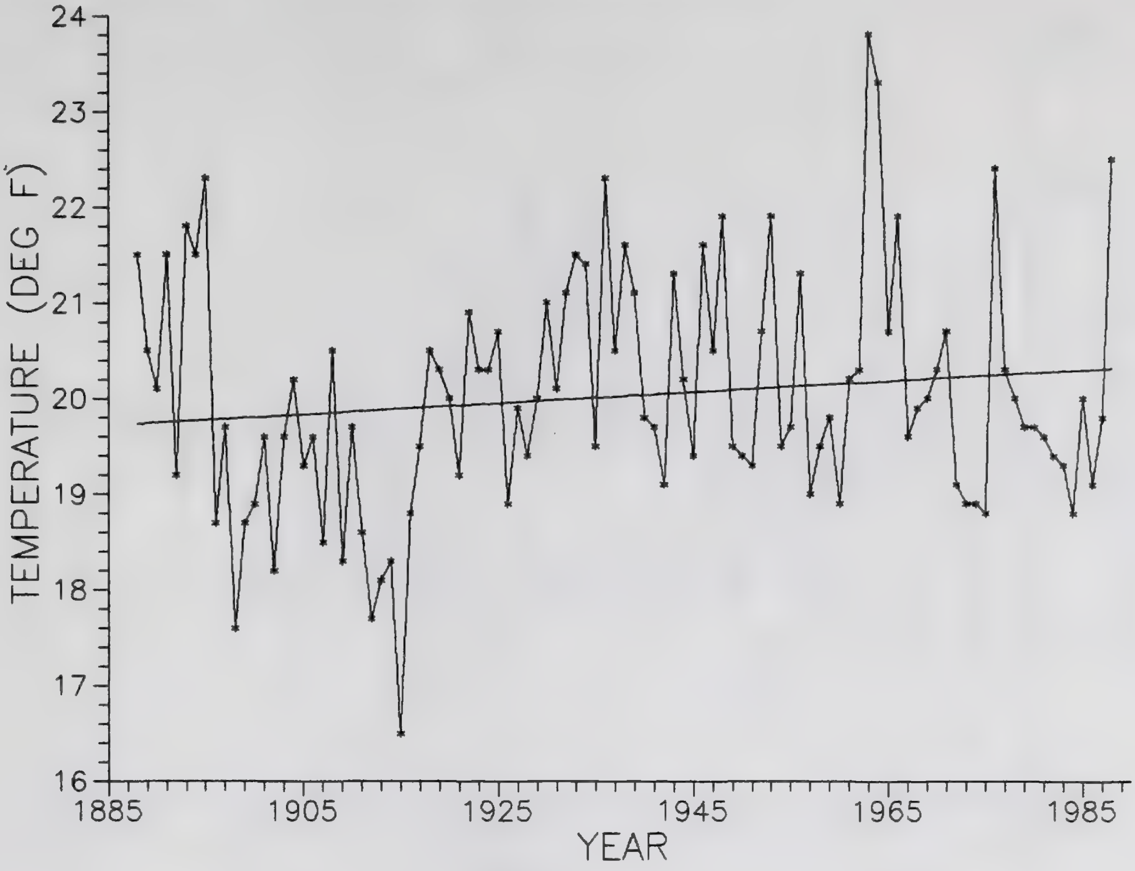

FIGURE 6. Annual mean daily temperature range, mean daily maximum – mean daily minimum, for indicated year, 1888-1988, for West Lafayette 6NW Indiana. Linear time trend for annual mean daily temperature range + 0.006 deg F/yr (r = 0.14).

to complete 1988) are shown in Figure 2. Note that the total range in the annual means is 8.0 deg F, from a low of 45.8 deg F in 1917 to a high of 53.8 in 1931. This is more than three times the total range of about 2.4 deg F in Hansen and Lebedeff's (1987) annual mean temperatures for the Northern Hemisphere. The linear trends are not significant (slopes of + 0.007, + 0.004, and + 0.001 deg F/yr, respectively, with correlation coefficients (r) of 0.13, 0.08, and 0.02). Although there is a visible upward trend since 1979, one can see similar historical short period trends from below the 101-yr trend line to above it. The data in Figure 2 were also fitted with a 10th order polynomial which smoothed the pattern to show cooling from about 1938 to 1978 followed by warming. However, multiple correlation coefficients (0.52, 0.42, and 0.31 for the annual mean daily maximum, mean, and mean daily minimum temperatures, respectively) were nonsignificant, indicating the folly of predicting future trends, especially with the distorted tails of the polynomial regression fit.

The January daily mean maximum and daily mean minimum temperatures for the last 101 years were plotted in Figure 3. The downward trend in the mean daily maximum temperature of – 0.04 deg F/yr or – 4.0 deg F in the 101-yr period was the only linear trend (r = – 0.20) significant at the 0.05 level reported in this paper. Yet the trend was associated with only 4% of the year-to-year variability in the mean daily maximum temperatures. The January mean daily

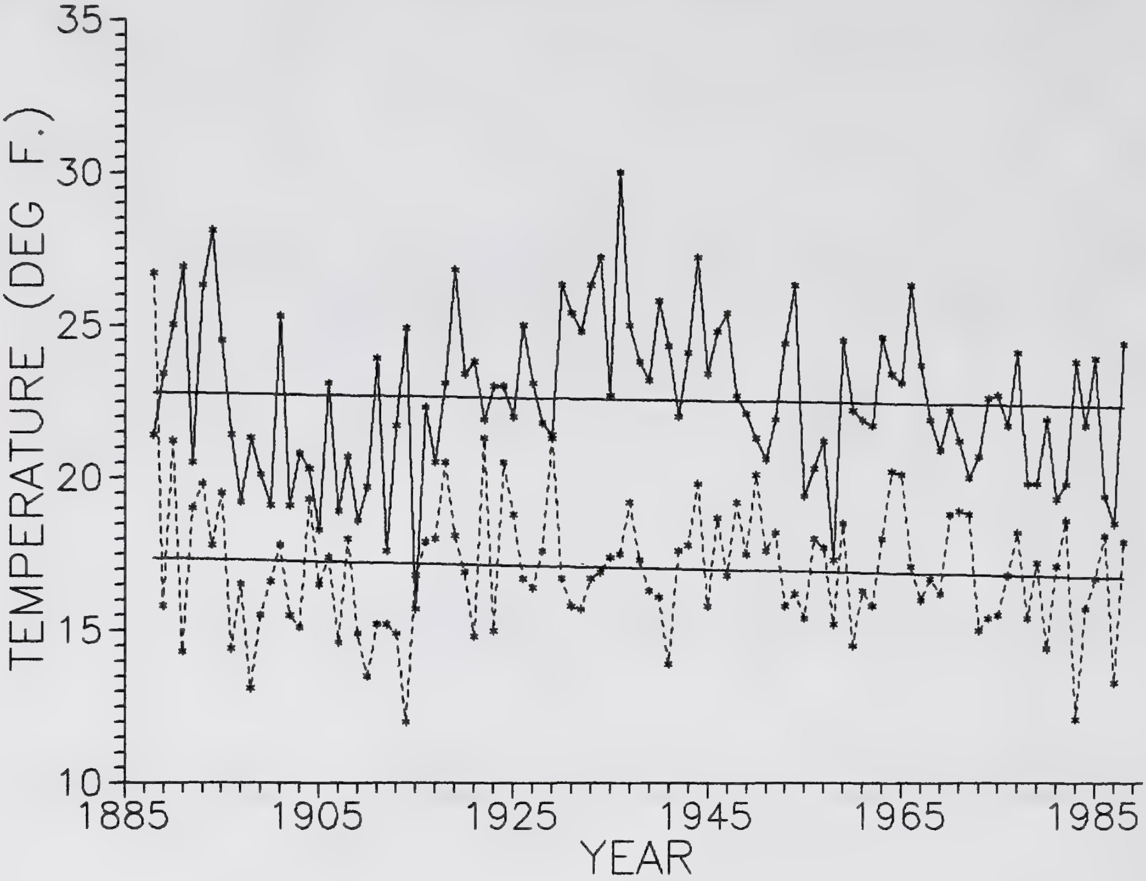

FIGURE 7. January (bottom) and July (top) mean daily temperature ranges, mean daily maximum – mean daily minimum, for indicated year, 1888-1988, for West Lafayette 6NW Indiana. Linear time trend in mean daily temperature range for January − 0.006 deg F/yr (r = − 0.09) and for July − 0.005 deg F/yr (r = − 0.05).

minimum temperatures also showed a downward (but nonsignificant) trend (− 0.03 deg F/yr, r = − 0.15).

The July mean daily maximum and mean daily minimum temperatures (Figure 4) showed no significant linear time trend (slopes − 0.004 and + 0.001 deg F/yr.) The fraction of the variance in the time series associated with regression was 0.001 for both the mean daily maximum and mean daily minimum temperatures.

The summer mean daily maximum and mean daily minimum temperatures (Figure 5) also showed no significant linear time trend over the last 101 year (slopes of − 0.0006 and − 0.003 deg F/yr). Note that at West Lafayette 6NW the summer of 1988 was not the hottest of record. It averaged below those of 1936, 1934, and 1933. The mean daily maximum temperature was 91.1 deg F in 1936 compared to 87.5 in 1988.

The annual mean daily temperature range was plotted for each year in Figure 6. Instead of the range decreasing, as was hypothesized with an enhanced atmospheric greenhouse effect, the range increased 0.006 deg F/yr. Again, the trend was nonsignificant (r = 0.14).

The range between the mean daily maximum and mean daily minimum temperatures for both January and July was plotted in Figure 7. Neither time

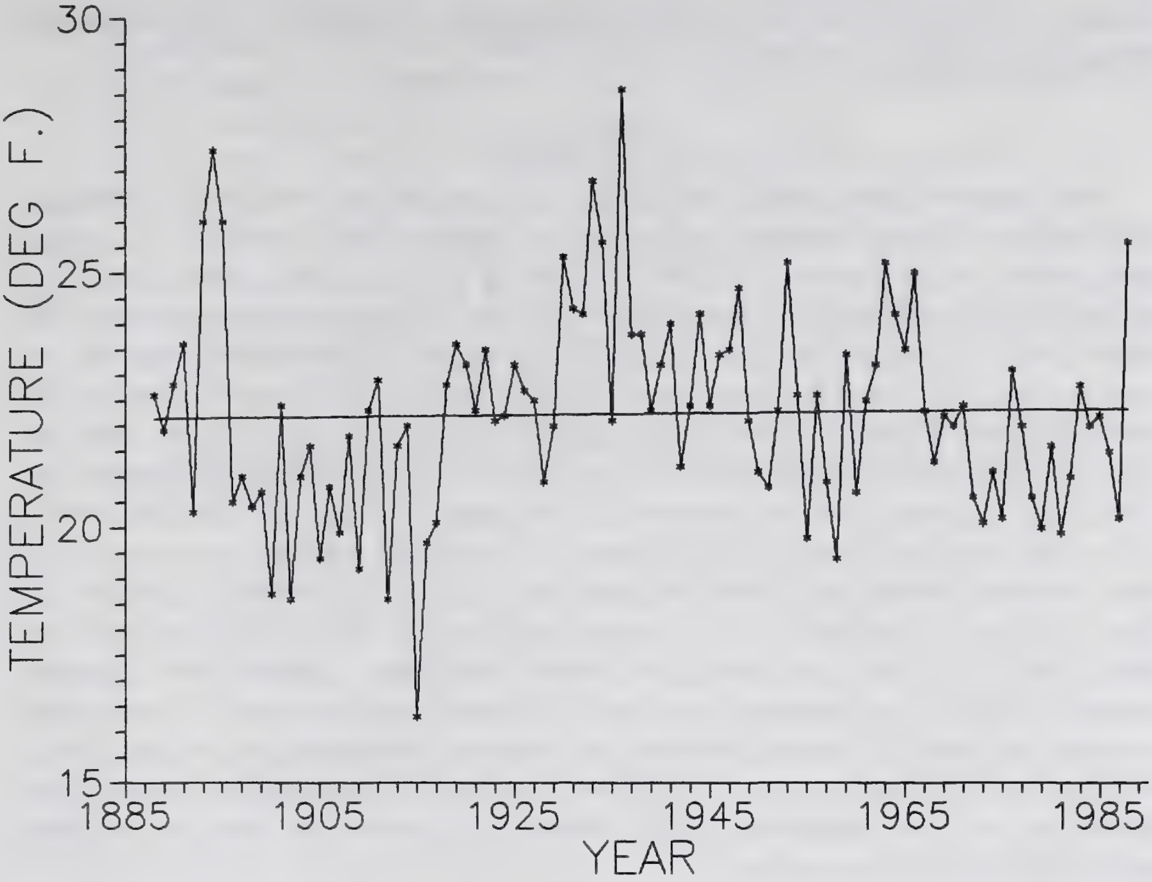

FIGURE 8. Summer mean daily temperature range, mean daily maximum – mean daily minimum, for indicated year, 1888-1988, for West Lafayette 6NW Indiana. Linear time trend in mean daily temperature range + 0.002 deg F/yr (r = 0.03).

trend was significant. Similarly, there was no significant linear time trend in the summer temperature range (Figure 8). The hypothesized decrease in the mean daily temperature range with an enhanced atmospheric greenhouse effect has not occurred, at least at West Lafayette, Indiana.

In the July and summer time series, there appears to be a tendency for an upward trend (greater diurnal temperature range) up to 1936 and then downward from that time. The diurnal range is greatly affected by drought. If there were ample soil moisture, the net radiation from the shortwave and longwave radiation balance would be expended mainly in latent heat, or in evaporating water from the soil and plants (transpiration). With low soil moisture, the net radiation is expended more in sensible heat (i.e., warming the air), and maximum temperatures are high. Also, during a drought situation, usually there is less water vapor in the atmosphere, and this decrease in one of the important atmospheric greenhouse gases allows less longwave radiation to be absorbed and reradiated than would occur with higher atmospheric humidity. This results in lower minimum temperatures. Thus, maximum air temperatures are higher and minimum air temperatures lower during droughts than those observed when there is adequate soil moisture. The occurrence of droughts produces greater variance about any trend in the mean daily temperature range and reduces the chance of finding a significant trend caused by an enhanced atmospheric greenhouse effect caused by the dry air gasses. The hypothesis that the diurnal temperature range will decrease as a response to an enhanced greenhouse effect should be tested in a marine climate not subject to droughts.

SUMMARY

The reported hemispheric and global air temperature trends are not representative of the natural climatic regime, but rather reflect the effect of a disproportionately large number of WWR stations in growing urban areas. Karl and Jones (1989) have confirmed this for the U.S. annual mean air temperatures. The examination of air temperature records for a single rural climatological station, independently adjusted for non-climatic biases, showed no climatic warming. The variability in the time series decreases as one proceeds from the monthly (January and July) to the seasonal and annual temperature means for a single station. This variability decreases even further for the hemispheric and global averages, which makes any temperature time trends more obvious and perhaps more important than deserved, unless the urban temperature bias can be properly evaluated. Of the 13 different temperature time series examined for West Lafayette 6NW Indiana, there was only one significant linear trend from 1888 to 1988 (January mean daily maximum temperature), and that trend was downward. There is little evidence for climatic warming in northern Indiana, which can be used as a proxy for the northern hemisphere. In addition, the diurnal temperature range is not decreasing in West Lafayette 6NW Indiana, as it should be with an enhanced atmospheric greenhouse effect.

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RELATION OF ORGANIC MATTER CONTENT TO TEXTURE AND COLOR OF INDIANA SOILS

D. P. Franzmeier
Department of Agronomy
Purdue University
West Lafayette, Indiana 47907

INTRODUCTION

Organic matter is an important constituent of soils, because it has a high capacity for absorbing water, nutrients, and some agricultural chemicals such as herbicides. It also binds mineral particles together to form stable aggregates that give the soil favorable physical properties.

There is a general relationship between the organic matter content of the surface horizon of a soil and its color and texture. The term *organic matter* refers to the remains of plant and animal tissue in the soil. *Organic carbon (C)* refers to the carbon component of organic matter, which is about one-half the mass of organic matter. In the field, soil texture can be estimated by feel, and color can be determined by comparing the soil with standard Munsell color charts. Then, if the relationship between these properties and organic C were defined, one could use it with field estimates of color and texture to estimate the organic matter content of the soil. Some guidelines are available to help make this estimate. Alexander (1971) published a color chart for estimating the organic matter content of soil plow layers in Illinois with medium texture, and Steinhardt and Franzmeier (1979) summarized the relationship of organic matter content and soil color for silt loam soils in Indiana. Also, Fernandez, *et al.* (1988) showed that there is a very close relationship between Munsell color value (darkness) and organic matter content in a toposequence of soils, most of which had silt loam textures.

During the Cooperative Soil Survey of Indiana, the Purdue Soil Characterization Laboratory analyzed many soil pedon (profiles) that soil scientists had selected to represent a particular soil series in a county. These data can be summarized to establish the pertinent relationships for all soils of the State. Thus, the main objectives of this study were to (1) characterize the relationship of soil texture and color to soil organic C content and to (2) learn if this relationship was the same across the State and for various natural drainage classes.

METHODS AND MATERIALS

The Purdue Soil Characterization Laboratory analyzed about 1660 pedons between 1968 and 1988. In this laboratory, soil organic carbon (C) was determined by oxidation with sulfuric acid and potassium dichromate, using external heat according to the Mebius method, and particle-size distribution (texture) was determined by the pipet method and sieving. These methods were described by Franzmeier, *et al.* (1977). These data have been published in a series of Experiment Station Bulletins. The latest one is listed under Indiana Soil Survey Staff (1988), and it contains a listing of 10 previous bulletins.

TABLE 1. Organic C content of Ap horizons by soil texture and color.

Texture	Statistic[2]	Color (value/chroma for 10YR hue)						
		2/1	2/2	3/1	3/2	3/3	4/2	4/3
					%C			
Fine sand and sand	$\bar{x}$	—	—	—	0.75	0.41	0.64	0.37
	N	—	—	—	1	9	1	9
	SD	—	—	—	—	0.11	—	0.11
Loamy fine sand and loamy sand	$\bar{x}$	2.46	0.86	1.47	0.82	0.81	0.72	0.54
	N	6	1	6	16	9	10	16
	SD	1.25	—	0.53	0.29	0.28	0.25	0.14
Fine sandy loam and sandy loam	$\bar{x}$	2.24	1.54	1.47	1.31	0.94	0.92	0.87
	N	21	12	22	28	19	38	42
	SD	1.05	0.77	0.61	0.38	0.28	0.32	0.31
Loam	$\bar{x}$	3.40	1.72	2.24	1.67	1.74	1.28	1.17
	N	21	6	21	23	13	40	28
	SD	1.95	0.24	0.99	0.56	0.97	0.29	0.43
Silt loam[1]	$\bar{x}$	3.19	2.12	2.47	1.77	1.82	1.31	1.17
	N	21	11	36	62	26	155	246
	SD	1.17	0.58	0.79	0.41	0.65	0.42	0.35
Clay loam	$\bar{x}$	3.70	—	2.05	1.83	—	1.20	1.17
	N	10	—	7	7	—	6	7
	SD	2.86	—	0.44	0.31	—	0.27	0.24
Silty clay loam	$\bar{x}$	3.49	2.43	2.67	2.22	2.05	1.33	1.23
	N	32	3	32	28	6	16	10
	SD	1.28	0.25	0.75	0.57	0.65	0.45	0.24
Silty clay and clay	$\bar{x}$	3.73	2.37	3.06	2.78	—	2.22	1.65
	N	4	2	9	7	—	6	3
	SD	0.78	0.30	0.71	0.79	—	1.19	0.57
[1] Other values for silt loam.		10YR5/2		10YR5/3		10YR5/4		
	$\bar{x}$	0.99		1.07		1.09		
	N	38		42		18		
	SD	0.27		0.38		0.52		

[2] $\bar{x}$ = mean; N = number of samples; and SD = standard deviation.

The laboratory data and field morphological descriptions were placed in a data base management system (Knowledgeman, version 2.01), which was used to sort data by various parameters and to determine mean and standard deviation. Analysis of variance and multiple linear regression were done using SAS (1985). In addition, a Student-Newman-Keuls means separation test was performed on the data in Table 3. The test was adopted for computer use from standard texts by statisticians in the Agronomy Department.

RESULTS AND DISCUSSION

The data for Ap horizons with 10YR hue from all regions of the State were first stratified by USDA texture class and color (Table 1). This grouping included 1268 samples; it excluded Ap horizons with hue other than 10YR and those from soils that had never been plowed. The average standard deviation (SD) in Table 1 was 1.48 %C for soils with 10YR 2/1 color, the darkest color on the commonly

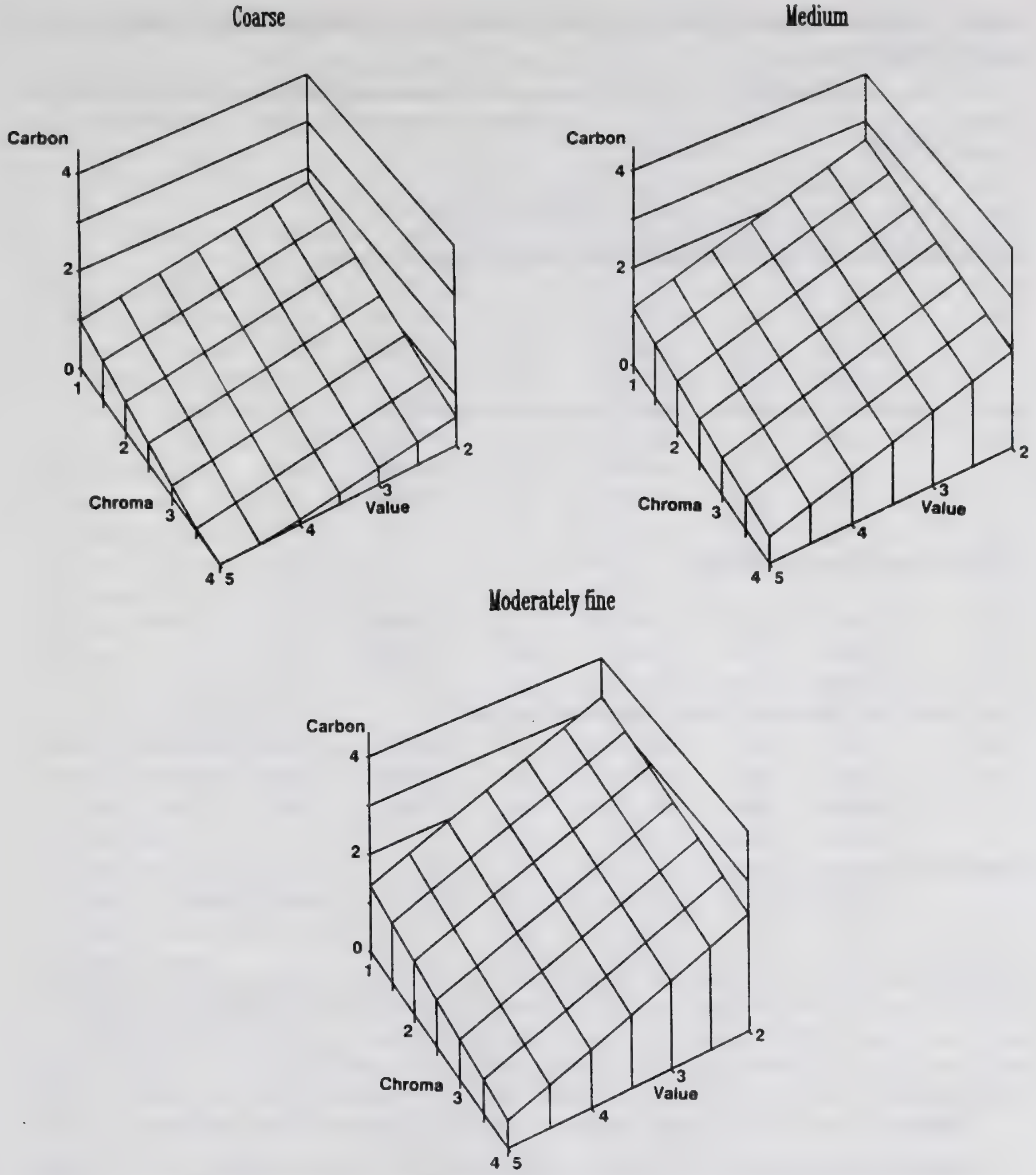

FIGURE 1. Graphs showing the effects of color value and chroma on organic C content (%) as derived from regression equations for soils in three texture classes.

used chart, and 0.46 %C for all other colors. Soils with a few percent of organic C are as dark as 10YR 2/1, and more organic C does not result in darker colors. Soils recognized as organic soils in the field were not included in the study. Many of them, however, have 10YR 2/1 colors.

Next, the USDA texture classes were combined into five larger classes (Table 2) used in soil judging (Yahner, *et al.*, 1980). This table is arranged like the Munsell color charts, with low color values and chromas (dark colors) in the lower left corner. The data were then smoothed by calculating a multiple linear regression with organic C as the dependent variable and value and chroma as independent variables for each texture group. The resulting equations are listed below by texture group:

TABLE 2. Mean organic C content of Ap horizons by soil texture group and soil color (10YR hue).

Color value	Color chroma							
	1		2		3		4	
	%C (number of samples)							
Sand, fine sand, loamy fine sand, and loamy sand (Coarse)								
5	—		—		0.6(2)	0.2*	0.3(3)	−0.2
4	—		0.7(11)	0.8	0.5(25)	0.5	0.5(3)	0.1
3	1.5(6)	1.5	0.8(17)	1.1	0.6(18)	0.7	—	
2	2.5(6)	1.7	0.9(1)	1.3	—		—	
Sandy loam and fine sandy loam (Moderately coarse)								
5	—		0.4(1)	0.7	0.7(3)	0.4	—	
4	1.8(2)	1.3	0.9(38)	1.0	0.9(42)	0.8	0.7(2)	0.5
3	1.5(22)	1.6	1.3(28)	1.4	0.9(19)	1.1	—	
2	2.2(21)	2.0	1.5(12)	1.7	—		—	
Silt loam and loam (Medium)								
5	—		1.0(39)	1.0	1.1(42)	0.7	1.1(19)	0.5
4	1.2(3)	1.7	1.3(195)	1.4	1.2(274)	1.2	1.1(19)	1.0
3	2.4(57)	2.1	1.7(85)	1.9	1.8(39)	1.7	—	
2	3.3(42)	2.6	2.0(17)	2.4	—		—	
Clay loam and silty clay loam (Moderately fine)								
5	—		1.5(1)	1.1	1.4(5)	0.8	1.0(1)	0.5
4	1.6(5)	2.0	1.3(22)	1.7	1.2(17)	1.4	1.0(2)	−1.1
3	2.6(39)	2.6	2.1(35)	2.3	2.1(6)	2.0	—	
2	3.5(42)	3.2	2.4(3)	2.9	—		—	
Clay and silty clay (Fine)								
4	2.5(2)	2.5	2.2(6)	2.0	1.7(3)	1.5	—	
3	3.1(9)	3.1	2.8(7)	2.5	—		—	
2	3.7(4)	3.6	2.4(2)	3.1	—		—	

* Actual mean, (number of samples), and values calculated from regression equations.

Coarse: $C = 2.56 - 0.241 \text{ Value} - 0.377 \text{ Chroma}, R^2 = 0.47$.

Moderately coarse: $C = 2.90 - 0.337 \text{ Value} - 0.267 \text{ Chroma}, R^2 = 0.38$.

Medium: $C = 3.77 - 0.473 \text{ Value} - 0.222 \text{ Chroma}, R^2 = 0.45$.

Moderately fine: $C = 4.66 - 0.606 \text{ Value} - 0.274 \text{ Chroma}, R^2 = 0.31$.

Fine: $C = 5.18 - 0.532 \text{ Value} - 0.523 \text{ Chroma}, R^2 = 0.47$.

These equations were used to calculate organic C contents to give a smooth relationship with value and chroma (Table 2). They show three trends: 1) for a given color, soil organic C content increases with finer texture; 2) for a given texture and chroma, organic C increases with decreasing color value; and 3) for a given texture and color value, organic C increases with decreasing chroma. Some of the these relationships are shown graphically in Figure 1.

The question of whether the relationship of organic C content with soil texture and color is the same across the entire State was then explored. The only texture that is common to all soil regions (Franzmeier, *et al.*, 1989) of the State is silt loam, and the most common colors of silt loam Ap horizons are 10 YR 4/2 and

TABLE 3. Organic C content of silt loam Ap horizons by soil color and soil region.

Soil region, parent material, and representative soil series	Soil color					
	10YR4/2			10YR4/3		
	x̄	N	SD	x̄	N	SD
	%C			%C		
2, Illinoian lacustrine deposits, Bartle	1.02	13	0.18	1.03	24	0.27
2, Wisconsin lacustrine deposits, Markland	1.37	3	0.45	1.56	1	—
3, Alluvial deposits Genesee	1.24	22	0.37	1.14	41	0.31
3, Terrace deposits, Fox	1.11	33	0.29	1.10	57	0.26
5, Deep loess, Sylvan	1.37	8	0.67	1.03	16	0.28
6, Loamy Wisconsin till (Cary), Crosier	1.08	4	0.42	0.82	2	0.16
7, Clayey Wisconsin till (Cary), Blount	1.46	19	0.42	1.41	12	0.16
8, Loamy Wisconsin till (Tazewell), Crosby	1.38	24	0.34	1.23	30	0.45
9, Loess and loamy Wisconsin till (Tazewell), Fincatle	1.38	14	0.46	1.07	9	0.38
10, Loess and Illinoian till, Cincinnati	1.34	10	0.53	1.22	34	0.34
11, Loess and weathered siltstone and shale, Wellston	1.26	1	—	1.24	9	0.18
12, Loess and weathered limestone, Crider	1.39	1	—	1.24	14	0.25
13, Loess and weathered shale and limestone, Eden	1.83	2	0.01	1.88*	5	0.39

*Mean organic C content of Eden soils with 10YR4/3 color is different at the 1% level from all other means except for the Markland and Blount groups. No other means are significantly different at that level.

10YR 4/3. Therefore, this texture and these colors were used to examine the relationship. The number of samples in each class stratified by soil region, texture, and color ranged from 1 to 57 (Table 3). To test for differences among these classes, an analysis of variance test adjusted for unequal numbers of observations and a mean separation test were used. These tests showed very few differences. Only the Eden group (soil region 13) with color of 10YR 4/3, which contained only five samples, was different from several other groups as noted at the bottom of Table 3. Thus, in general, there were no great differences due to soil region for the silt loam soils. This might be expected, because most of the silt loam Ap horizons were derived from loess, which was quite similar across the State. More detailed investigations, however, might show some differences.

The data for a set of soils with a certain color and texture was also examined to learn if the naturally wet soils have the same organic C content as the naturally

TABLE 4. Organic C content of Ap horizons by soil texture and color for somewhat poorly, poorly, and very poorly drained soils.

Texture	Statistic[2]	Color (value/chroma for 10YR hue)						
		2/1	2/2	3/1	3/2	3/3	4/2	4/3
					%C			
Loamy fine sand and loamy sand	$\bar{x}$	—	—	—	0.79	—	—	—
	N	—	—	—	3	—	—	—
	SD	—	—	—	0.05	—	—	—
Fine sandy loam and sandy loam	$\bar{x}$	2.48	1.58	1.64	1.35	0.97	0.78	0.83
	N	17	2	13	16	3	16	3
	SD	1.02	0.57	0.72	0.42	0.18	0.21	0.27
Loam	$\bar{x}$	3.35	2.13	2.44	1.97	—	1.29	1.26
	N	19	1	18	13	—	21	3
	SD	2.04	—	0.92	0.52	—	0.30	0.36
Silt loam[1]	$\bar{x}$	3.21	2.16	2.50	1.84	1.54	1.25	1.01
	N	20	5	30	32	6	105	32
	SD	1.19	0.87	0.70	0.48	0.37	0.40	0.26
Silty clay loam	$\bar{x}$	3.52	—	2.67	2.26	—	1.38	—
	N	29	—	32	22	—	11	—
	SD	1.34	—	0.75	0.64	—	0.35	—
[1] Other values for silt loam		10YR5/2		10YR5/3		10YR5/4		
	$\bar{x}$	0.98		1.04		0.91		
	N	37		27		7		
	SD	0.26		0.26		0.15		

[2] $\bar{x}$ = mean; N = number of samples; and SD = standard deviation.

dry ones. The detailed results are in Table 4 for the wetter soils and in Table 5 for the dryer ones. The number of samples in the various classes again was highly variable. The standard deviations in these tables are mostly < 0.75 %C, except for the "wet" soils with 10YR 2/1 color for which all the standard deviations are > 1.0 %C. Thus, the variability for 10YR 2/1 soils noted in Table 1 is mainly due to the wetter soils, not the better drained ones.

In Table 6, the results are compared for classes, where both the wet and the dry members had five or more samples. There is little difference due to natural drainage, but for the darker soil colors (10YR 2/2, 3/1, 3/2), the wet soils consistently contain more organic C.

To apply this information in soil management, one must know the organic *matter* content of the soil. For example, the label on some herbicides lists application rates according to soil organic matter content. The organic *matter* values in Table 7 were calculated by multiplying the calculated (smoothed) values for organic *carbon* in Table 2 by two. The texture groupings in that table are familiar to many people, who have learned about soil properties in the high school soil judging program. This table can be used to estimate organic matter contents. A laboratory determination should be done, if more accurate informaiton is required, especially for dark-color Ap horizons of poorly drained soils.

TABLE 5. Organic C content of Ap horizons by soil texture and color for moderately well, well, and excessively drained soils.

Texture	**Statistic**[2]	**Color (value/chroma for 10YR hue)**						
		2/1	**2/2**	**3/1**	**3/2**	**3/3**	**4/2**	**4/3**
		%C						
Loamy fine sand and loamy sand	x̄	—	—	—	0.83	—	—	0.54
	N	—	—	—	13	—	—	16
	SD	—	—	—	0.32	—	—	0.14
Fine sandy loam and sandy loam	x̄	1.19	1.53	1.23	1.25	0.93	1.02	0.88
	N	4	10	9	12	16	22	39
	SD	0.07	0.83	0.28	0.33	0.30	0.35	0.32
Loam	x̄	3.82	1.63	1.08	1.29	1.74	1.26	1.16
	N	2	5	3	10	13	19	25
	SD	0.68	0.14	0.40	0.36	0.97	0.28	0.44
Silt loam[1]	x̄	2.90	2.09	2.36	1.71	1.90	1.45	1.19
	N	1	6	6	30	20	49	214
	SD	—	0.28	1.22	0.30	0.70	0.45	0.36
Silty clay loam	x̄	3.18	—	—	2.07	—	1.22	—
	N	3	—	—	6	—	5	—
	SD	0.42	—	—	0.17	—	0.64	—
[1] Other values for silt loam		10YR5/2		10YR5/3		10YR5/4		
	x̄	1.40		1.12		1.21		
	N	1		15		11		
	SD	—		0.55		0.64		

[2] x̄ = mean; N = number of samples; and SD = standard deviation.

TABLE 6. Organic C content by natural drainage group, soil texture, and soil color.[1]

Texture	**Drainage group**[2]	**Color (value/chroma for 10YR hue)**					
		2/2	**3/1**	**3/2**	**3/3**	**4/2**	**4/3**
		%C					
Fine sandy loam and sandy loam	Wet	—	1.64	1.35	—	0.78	
	Dry	—	1.23	1.25	—	1.02	—
Loam	Wet	—	—	1.97	—	1.29	—
	Dry	—	—	1.29	—	1.26	—
Silt loam	Wet	2.16	2.50	1.84	1.54	1.25	1.01
	Dry	2.09	2.36	1.71	1.90	1.45	1.19
Silty clay loam	Wet	—	—	2.26	—	1.38	—
	Dry	—	—	2.07	—	1.22	—

[1] Classes with more than four wet and four dry samples are listed.

[2] "Wet" soils are somewhat poorly, poorly, or very poorly drained; "Dry" soils are excessively, well, or moderately well drained.

TABLE 7. Mean organic matter content of Ap horizons by soil texture group and soil color (10YR hue) derived from calculated values in Table 2.

Color value	Color chroma			
	1	2	3	4
	%C (number of samples)			
Sand, fine sand, loamy fine sand, and loamy sand (Coarse)				
5	—	—	0.4	0.1
4	—	1.6	1.0	0.2
3	3.0	2.2	1.4	—
2	3.4	2.6	—	—
Sandy loam and fine sandy loam (Moderately coarse)				
5	—	1.4	0.8	—
4	2.6	2.0	1.6	1.0
3	3.2	2.8	2.2	—
2	4.0	3.4	—	—
Silt loam and loam (Medium)				
5	—	2.0	1.4	1.0
4	3.4	2.8	2.4	2.0
3	4.2	3.8	3.4	—
2	5.2	4.8	—	—
Clay loam and silty clay loam (Moderately fine)				
5	—	2.2	1.6	1.0
4	4.0	3.4	2.8	2.2
3	5.2	4.6	4.0	—
2	6.4	5.4	—	—
Clay and silty clay (Fine)				
4	5.0	4.0	3.0	—
3	6.2	5.0	—	—
2	7.2	6.2	—	—

CONCLUSIONS

Soil organic matter content of Ap horizons (plow layers) increases with increasing clay content, decreasing color value, and decreasing color chroma. For dark grayish brown to brownish (10YR 4/2 and 4/3) silt loam soils, which are very common in Indiana, the effects of location in the State and of natural drainage on the content of organic C were small. The deviation from the mean was relatively large for poorly drained soils with dark color and relatively small for lighter colored poorly drained soils and all better drained soils. The relationships can be used to estimate the organic matter content of many soils, but laboratory determinations may also be required.

ACKNOWLEDGMENTS

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INTERACTIONS BETWEEN SUMMER STORMS AND PHOTOCHEMICAL AIR QUALITY IN SW INDIANA

R. H. Grant
Department of Agronomy
Purdue University
West Lafayette, Indiana 47907

INTRODUCTION

Acidic precipitation, although not now considered a major threat to ecosystems in the Midwestern United States, remains an important measure of environmental quality. The identification of the sources of railfall acidity need to take into account the gaseous and particulate atmospheric environment, the type of storm event and its duration, the synoptic conditions surrounding the storm, and the trajectory of the storm prior to its activity over the site of interest. Nitrogen compounds in precipitation are generally not the primary sources of precipitation acidity in the eastern half of the United States, but previous work has indicated that 80% of the summer concentrations of nitrate are associated with hydrogen ion concentrations (Grant, 1988). Since nitric acid is derived from oxidation reactions involving nitrogenous aerosols and gasses, particulate and gaseous air quality are directly linked to precipitation acidity.

The gaseous nitrogen species present in the atmosphere are almost all highly reactive and have temperature sensitive kinetics, resulting in short atmospheric residence times. The residence time for NO_2 and NO is probably between 6 to 10 hours during the summer (Singh, 1987). Therefore, during the summer the gaseous concentrations of NO_2 and NO measured from the day prior to the time of the precipitation may represent the levels in the formation of nitric acid within the storm and consequently the nitrate ion in the precipitation. This relationship would be confused by local sources of NO. A relationship between NO_2 and NO and precipitation NO_3^- may also be masked by gaseous NO_3, HNO_3, N_2O_5, and HO_2NO_2 and particulate NO_3 that may be important in the formation of aqueous NO_3^- and gaseous HNO_3 (Singh, 1987). In addition, there could be non-chemical advective processes that may change atmospheric concentrations due to wind direction, turbulent mixing, and diffusion.

The nitrogen oxides in combination with sunlight and reactive non-methane hydrocarbons control the concentrations of ozone. The high levels of ozone near the earth's surface that occur during the day is indicative of the UV environment and the NO emission and NO_2 formed during the night. In this paper, NO_x equals NO + NO_2. The relationships between the concentrations of ozone, nitric oxide, and nitrogen dioxide and wind direction, amount of precipitation, type of storm producing precipitation, and the nitrate ion in the precipitation are discussed in this paper. PAN and non-methane hydrocarbons, although known to be important in the formation of ozone, were not considered due to lack of measurements.

MATERIALS AND METHODS

Measurements of hourly ozone, nitric oxide, and nitrogen dioxide concentrations as well as wind direction were made at the Southwest Purdue Agricultural

TABLE 1. Characteristics of the growing season mean daily air quality.

Specie	1986		1987		Combined	
	Mean[1]	% Capture[2]	Mean	% Capture	Mean	% Capture
NO_X	14.9	71	15.3	80	15.1	76
NO_2	11.0	66	11.5	68	11.2	67
NO	3.9	66	3.8	68	3.9	67
NO_2/NO	4.9	66	5.5	68	5.2	67
O_3	34.0	96	36.6	91	35.5	94

[1] Concentrations in ppb.

[2] Calculated as percent from # days with > 50% of the hours measured/total number of days in period.

Center by the Indiana Department of Environmental Management (IDEM) as part of the air quality network. The ozone concentration was determined by chemiluminescence. The nitrogen oxides were estimated by chemiluminescence using a CSI model 1600. It was assumed that the peroxyacetyl nitrate (PAN) and gaseous HNO_3, also measured by the analyzer, was significantly less than the nitrogen oxides at this rural site. Nitrogen dioxide was determined by reduction of the nitrogen oxides to nitric oxide. Quality assurance and control of the analyzers was maintained by the IDEM. Wind direction was measured at 7 m (4 m above a trailer).

Aerosols were collected using an Andersen five stage impactor located at a farm near Decker, Indiana, located 20 km from the Southwest Purdue Agricultural Center. Aerosol collections were made for 24 hour periods at a flow rate of 9440 cm^3s^{-1}, resulting in a sample volume of 1835 m^3. The sampler was mounted at a height of 7 m with a rectangular gabled roof over the intake resulting in an upper size limit for the sampler of approximately 30 μm (Hidy, 1984). The sampler had four stages of Whatman 41 filters which separated the aerosol into the size classes with effective cutoff diameters of 7, 3.3, 2, and 1.1 μm, and a last (backup) stage that had an effective cutoff diameter of approximately 0.05 μm. Aerosol samples were collected every three and four days (alternating) from 11 September 1985 to 4 December 1985 and every seven days from then until 23 September 1987 by PSI Energy. All filters were quality-assured before and after exposure and catalogued by the IDEM. Quality assurance involved the repeated weighing of desiccated filters for constancy.

The water-soluble nitrate concentation of the particle fractions was determined using standards of 5 and 10 ppm NO_3 and methods according to Grant and McFee (1989). Positive artifacts of nitrate are found on cellulose filters similar to the first four stages (Appel, *et al.,* 1979), probably resulting in overestimates of the true nitrate aerosol. Smaller positive artifacts have also been found for nitrate on quartz fiber filters like the backup filter (Spicer and Schumacher, 1977); however, other studies suggest substantial losses, if significant fractions of the particulate are in the form of ammonium nitrate (Forrest, *et al.,* 1980). Since much of the nitrate is expected to be present in submicron sizes, the estimates of the nitrate particulate concentration represent at best a lower limit estimate of nitrate particulates.

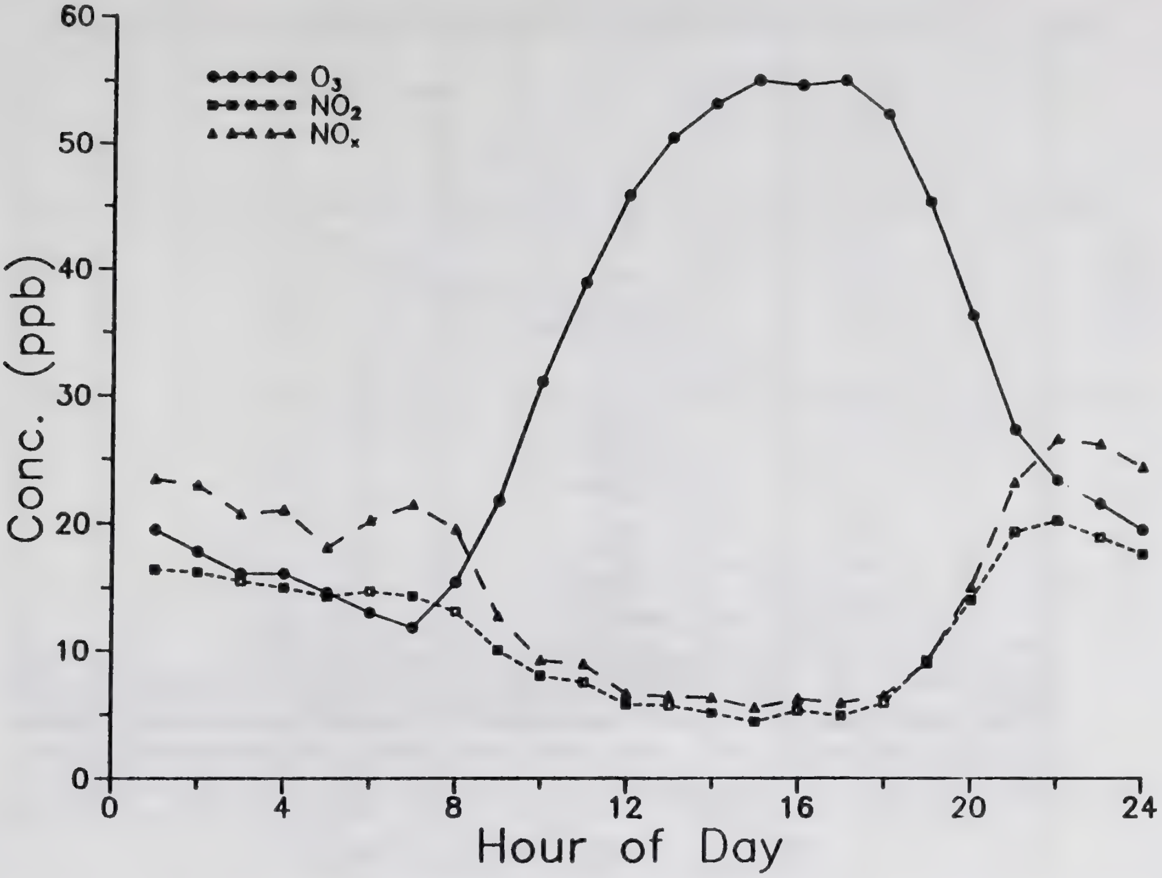

FIGURE 1. Hourly mean concentrations of O_3, NO_2, and NO for the 1986 growing season. O_3, NO_2, and NO are indicated by the solid, dashed, and dotted lines respectively. Note the increased NO levels around morning rush hour (8 AM EST) and in the nighttime.

Wet deposition of nitrate in the precipitation was determined as part of the National Atmospheric Deposition Program (NADP) weekly wet deposition collections. Quality control and assurance were maintained by the NADP Central Analytical Laboratory (Schroeder, *et al.,* 1986).

Each day of valid particle and gas concentration was classified as to whether precipitation occurred, how much precipitation occurred, and what kind of storm produced the precipitation. The precipitation days were identified by the occurrence of measurable precipitation at the Vincennes NADP weighting bucket raingauge. The type of storm producing the precipitation was determined by evaluating the synoptic National Weather Service daily weather maps. The storms were classified into air mass and frontal type storm precipitation. Air mass storms primarily occurred in the cyclone warm sector. Frontal storms included stationary, cold, and warm front storms.

RESULTS

The mean daily ozone, nitrogen dioxide, and nitric oxide concentrations were approximately the same for the 1986 and 1987 growing seasons (Table 1). During both seasons, the missing nitrogen compound measurements occurred mostly during the month of July.

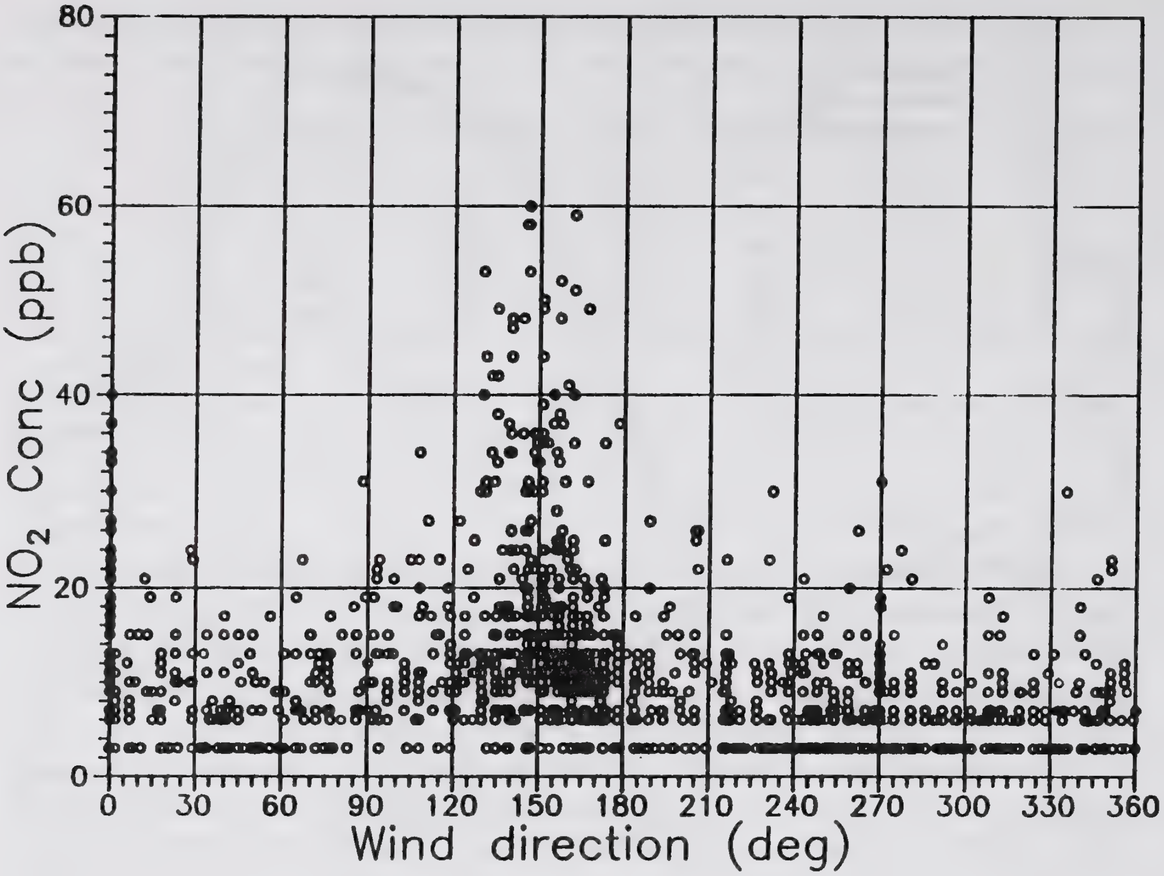

FIGURE 2. Influence of wind direction on the [NO_2] concentration at 7 m.

TABLE 2. Statistical test of the influence of precipitation on air quality specie concentrations.

Specie	Concentration Change	T	Prob > T	n
NO_x	−2.7[1]	−3.06	0.004	44
NO_2	−1.9[1]	−3.50	0.01	55
O_3	−0.8[2]	−0.63	0.53	62

[1] Mean daily concentration on day of precipitation less that on prior day.

[2] Mean daily concentration on day after precipitation less that on day of precipitation.

The hourly mean [NO], [NO_2], and [O_3] for the study period followed the expected diurnal pattern (Figure 1). The nitrogen oxides are high during the night and low during the day, while ozone is high during the day and low at night. The local peaks of [NO] at 700 h and possibly 2200 h may be influenced by local traffic emissions, when the surface boundary layer of the atmosphere is stable. The diurnal variation of [O_3] was largely due to the deposition of O_3 from the nocturnal boundary layer during the night and the mixing of the upper and convective boundary layer during the day (Shepson, *et al.*, 1992). The ratio of [NO_2] to [NO] provides an indication of the rapidly formed steady state relationship with [O_3] and is typically about 5. Results for the combined seasons fit this average condition well (Table 1).

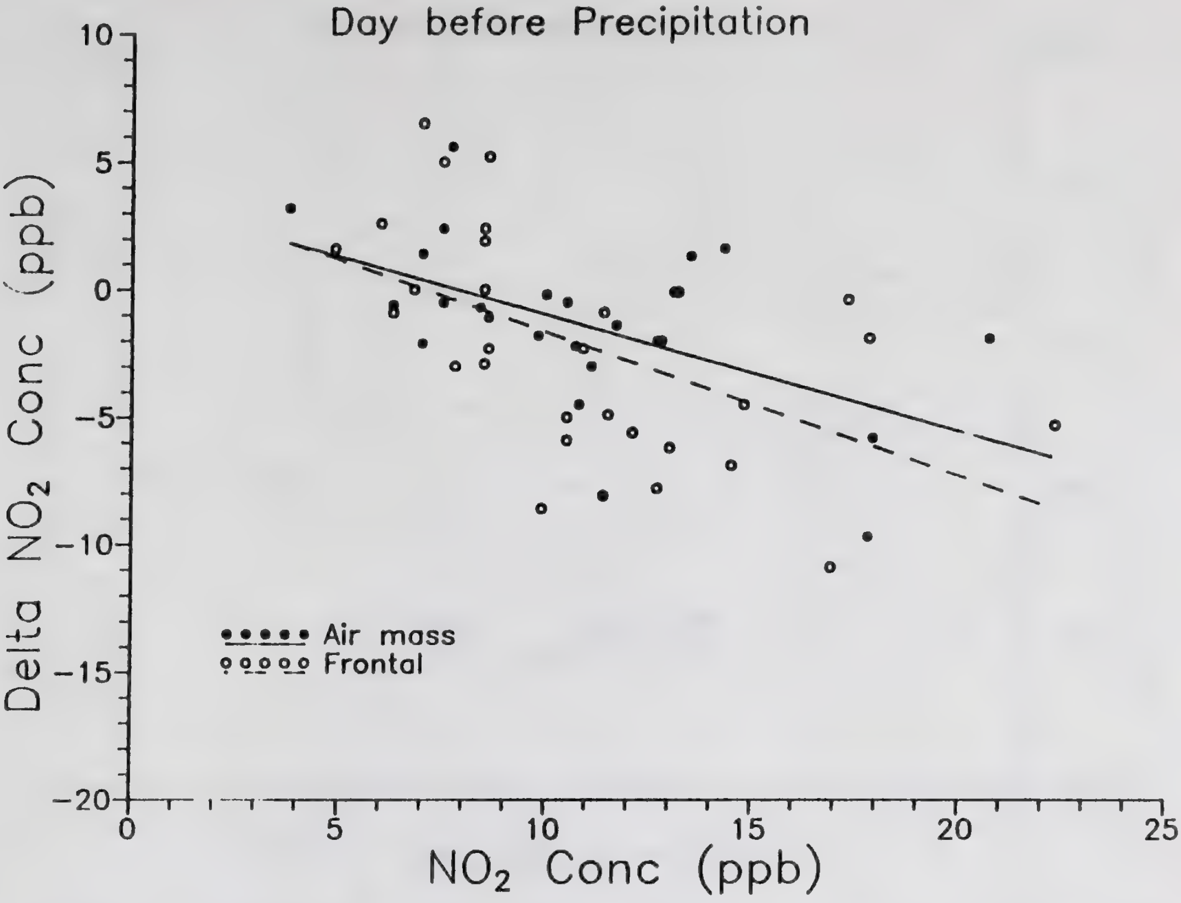

FIGURE 3. The change in $[NO_2]$ due to precipitation vs. the precipitation day $[NO_2]$. The closed circle and solid line represent the daily values for days in which the storms were within air masses and the corresponding linear regression respectively. The open circle and dashed line represent the daily values for days in which the storms were due to frontal passages and the corresponding linear regression reprectively. Note that the change is greatest when the $[NO_2]$ is above the seasonal mean of 11 ppb.

Of the 244 days of the study, 63 days had precipitation occurring. Of those days, 59% of the days were wet due to frontal storms, and 41% of the days were wet due to air mass convection storms. During the study period, 12 valid samples with NADP nitrate chemistry were collected.

Wind direction averaged 200 deg (North 0 degrees) for the combined two seasons with the mean direction during days of frontal and air mass type precipitation being 211 deg and 170 deg. The variation in the hourly mean $[NO_x]$ and $[NO_2]$ (e.g., Figure 2) over the study period varied with wind direction, while that of $[O_3]$ did not. The highest hourly mean $[NO_x]$ and $[NO_2]$ occurred when the wind was bearing between 160 and 180 degrees. This corresponds to the direction of a major source of $[NO_x]$ approximately 30 km from the sample site. This also corresponds with the mean direction of the air mass type storm typically derived during the summer from unstable moist maritime airmass air originating in the Gulf of Mexico or the Atlantic Ocean.

The occurrence of precipitation caused a 17% reduction in the $[NO_2]$ and a 18% reduction in $[NO_x]$ from the prior day mean (Tables 1 and 2). The change in $[NO_2]$

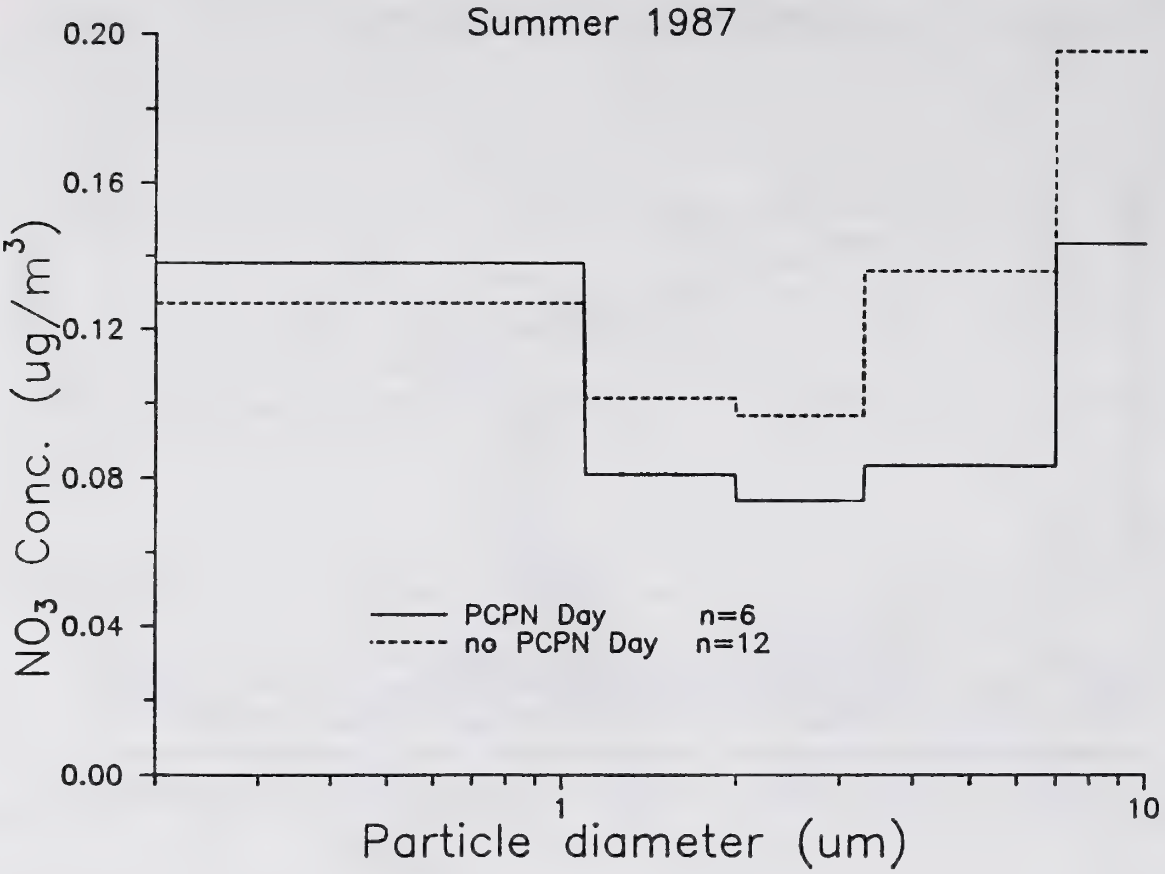

FIGURE 4. The influence of precipitation on the particulate [NO_3^-] distribution. The solid line represents the mean concentration distribution for particulate collections on days of precipitation. The dashed line represents the mean concentration distribution for particulate collections made on days during the study period in which no precipitation occurred.

and [NO_x] was greater for frontal storms than for air mass storms with a decrease of 2.2 ppb [NO_2] and 3.0 ppb [NO_x] with the frontal storm precipitation and a decrease of 1.4 ppb [NO_2] and 2.4 ppb [NO_x] with the air mass storm precipitation. The differences in magnitude and level of probable difference are probably due to the confounding of the [NO_2] and [NO_x] with the change in wind direction associated with passage of the front. Most frontal storms were cold fronts, resulting in a shift in the wind to the west and away from the bearings of the highest hourly means [NO_2] (presumably a major local source of the gas). Since the air mass storm differences also corresponded with continued southerly air flow, the influence of the local [NO_x] source should be continuous throughout the period of day before, day of, and day after precipitation. Thus, the changes [NO_2] and [NO_x] associated with air mass storm precipitation days probably better represent the storm effects on [NO_2] and [NO_x] levels in the near surface atmosphere. Results show that the change in [NO_2] was greater when the [NO_2] on the day before precipitation was higher, with distinct decreases in [NO_2] occurring when the [NO_2] on the day before precipitation was higher than the mean growing season concentration (Figure 3). This relationship was found for both air mass convective and frontal storms but again was more evident for frontal storm precipitation days. Therefore, shifts in the wind direction, affecting the influence of local sources

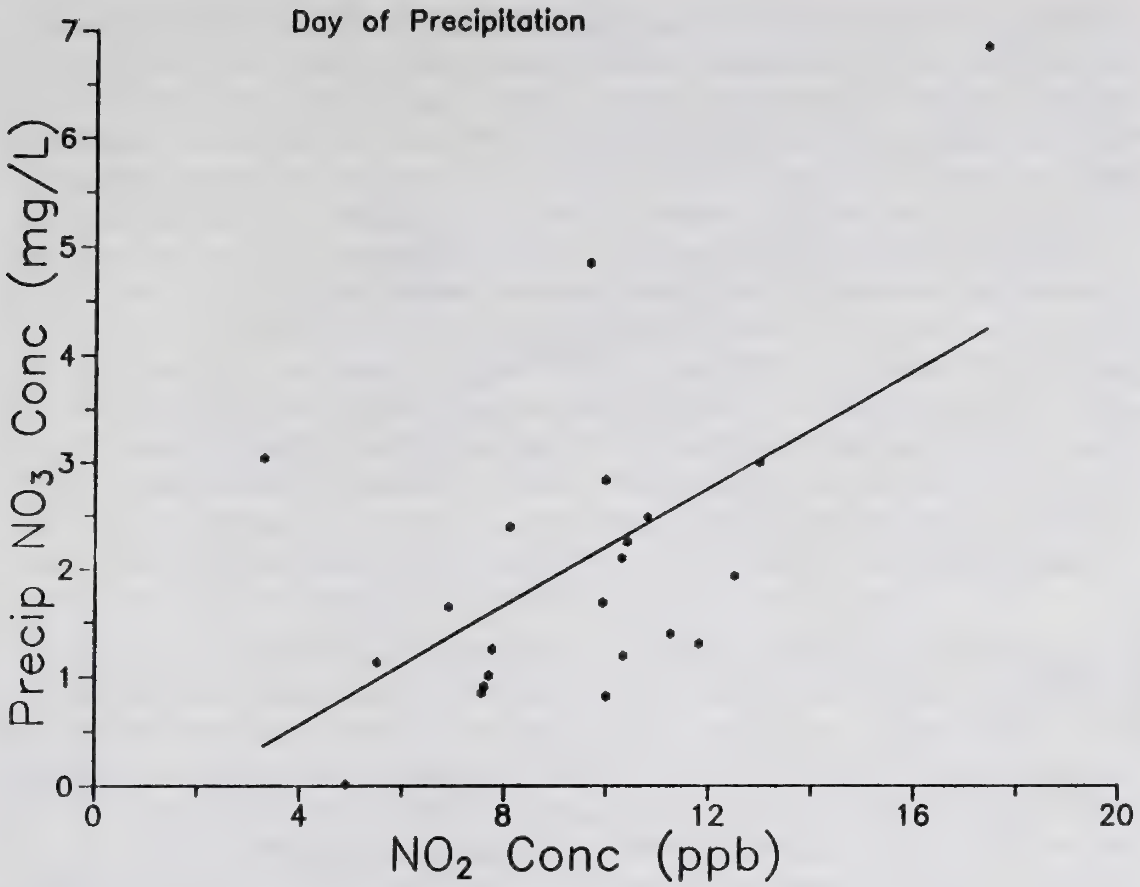

FIGURE 5. The relationship of $[NO_2]$ reductions associated with precipitation to precipitation $[NO_3^-]$.

of the $[NO_x]$ influence the strength of precipitation influence but do not account for most of the changes in $[NO_2]$ associated with the precipitation.

The change in $[NO_2]$ due to precipitation amount indicates that there is no trend in increased $[NO_2]$ reductions with increased precipitation. Considering only air mass convective storms, the range in the change in $[NO_2]$ does tend to decrease with increased precipitation, but this may solely be the small sample size. The range in the change in $[NO_2]$ in frontal storms shows much less decrease with increasing precipitation.

Although there were significant decreases in the mean $[NO_2]$ and $[NO_x]$ with the receipt of precipitation (Figure 3), these decreases did not carry over into the subsequent day after the precipitation. Daily mean concentrations of $[NO_2]$ and $[NO_x]$ for the day before and the day after precipitation were not significantly different. Thus, while a storm reduces the concentrations, it is only reduced for the day of precipitation.

The reduction in the mean $[NO_2]$ may be due to chemical oxidation reactions on the surface of the aerosols and precipitation droplets or vertical convection of the gas to the free troposphere through the updraft of the storm cell (Dickerson, *et al.*, 1987). Scavenging of NO_2 by the precipitation is negligible due to its low

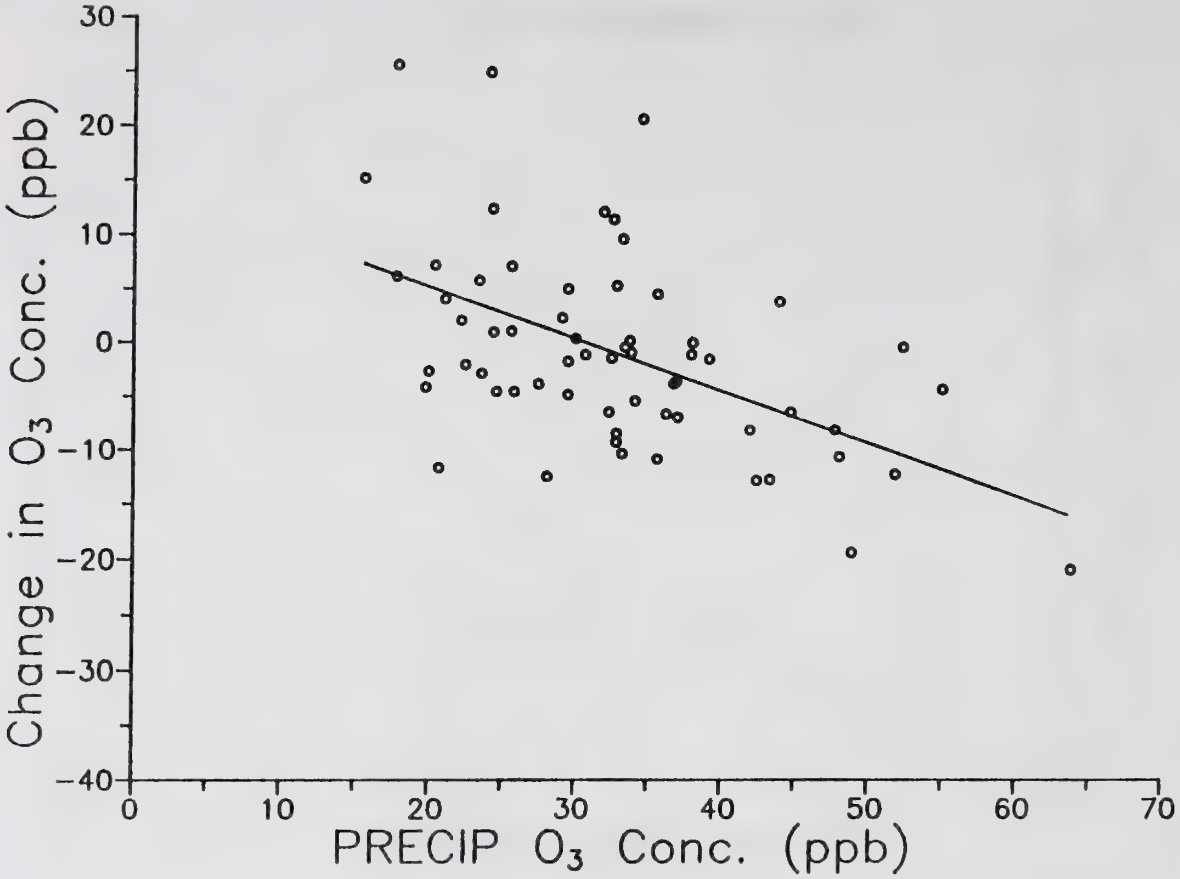

FIGURE 6. Effect of precipitation on $[O_3]$. Note that the precipitation does not influence the daily mean $[O_3]$ until the $[O_3]$ exceeds the seasonal mean of 35 ppb.

solubility in water (Pierson, *et al.*, 1987). Reductions in NO_2 through oxidation to HNO_3 during the daytime with subsequent scavenging of the HNO_3 by precipitation is possible since the solubility of HNO_3 in water is high, but no information on the $[HNO_3]$ was available at the study site. Noting that the $[NO_2]$ reduction due to storm activity seems to make a step change at about 10 ppb (Figure 3), and the seasonal mean $[NO_2]$ is 11 ppb (Table 1), it appears that the storm activity vents $[NO_2]$ to the free troposphere through the vertical convection updrafts of storm cells.

Comparing the precipitation $[NO_3]$ to the reduction in $[NO_2]$ shows that while the $[NO_2]$ is lower during the day of precipitation, it does not significantly influence the composition of the precipitation. A regression of the precipitation nitrate concentration by the change in $[NO_2]$ (Figure 5) yielded an r^2 of 0.12, while nitrate deposition on in $[NO_2]$ yielded an r^2 of only 0.06. Similar lack of correlation was found in comparing the wet concentration and deposition of NO_3 to the mean $[NO_2]$ during the day of precipitation. These results suggest that gaseous HNO_3 and particulate NO_3^- (and other nitrogenous compounds) are major contributors to the precipitation $[NO_3^-]$, and not gaseous NO_2. Furthermore, the lack of correlation between precipitation NO_3^- and reductions in $[NO_2]$ corresponding to days of precipitation indicates that the $[NO_2]$ reductions are probably primarily due to vertical convection.

Scavenging of particulate nitrate ($[NO_3^-]_p$) by the precipitation is expected, as rainout is an efficient scavenger of the aerosol (Stewart, *et al.*, 1990). For the summer of 1987, 18 aerosol collections were made with 33% collected during days of precipitation. the mean $[NO_3^-]_p$ present in the atmosphere of dry days was 0.21 mg m^{-3} while that in the atmosphere of the wet days was 0.15 mg m^{-3}. The 29% decrease in concentration between the non-precipitation and precipitation days was significant at the 0.20 level. The distribution of the $[NO_3^-]_p$ (Figure 4) showed that the smallest size fraction (< 1.1 μm diameter) was greater for the days of precipitation than for days without precipitation, while all other size fractions showed greater $[NO_3^-]_p$ for the days without precipitation than with precipitation. The only significantly different $[NO_3^-]_p$ size fractions were those particles $\geqslant 7$ μm and those $\geqslant 2$ μm and < 3 μm. The smalller $[NO_3^-]_p$ present in the larger fractions during days of precipitation are consistent with that expected after scavenging processes. Remembering the artifact problems, the larger size fractions of the collections have potential for substantial positive artifacts, while the last stage has the potential for negative artifacts. Therefore, due to the limited sampling of the particulates and the probable nitrate artifacts on the filters used, no conclusions as to the magnitude of the scavenging can be made.

As a result of the observed reduction in $[NO_2]$ on the day of precipitation, it may be expected that since O_3 is produced from NO_2, the $[O_3]$ on the day following the precipitation would also be reduced. While a reduction was indicated (Table 2), the reduction was not significant at even the 0.20 level using a students t-test. The $[O_3]$ apparently is not locally derived but is probably largely advected into the area. Reductions in O_3 associated with the occurance of precipitation was only evident when the $[O_3]$ was greater than the seasonal mean of 35 ppb (Figure 6). This 35 ppb level corresponds to the two growing season mean $[O_3]$ (Table 1). Mean daily ozone levels above the mean probably represent locally produced O_3 that is in addition to that advected across the region. As with the $[NO_2]$, storm activity probably vents the elevated (above regional average) $[O_3]$ to the free troposphere through the vertical convection updrafts of the storm cells.

CONCLUSIONS

Near surface hourly mean $[NO_2]$ is influenced by the direction of the wind. Winds coming from the southeast to south sector had higher $[NO_2]$ than the rest of the bearings, indicating a local source of NO and NO_2 to the Vincennes site. The high levels, however, were not always evident and were partly influenced by the time of day with night-time southerly winds producing higher levels than daytime southerly winds. The near surface hourly mean $[O_3]$ was not related to wind direction, in support of the contention that the majority of the O_3 is being advected into the area and not produced locally.

A significant reduction in daily mean $[NO_2]$ occurred on the day of precipitation. This indicates a local source of NO. The $[NO_2]$ reduction did not correspond to higher precipitation concentrations or depositions of $[NO_3^-]$. Therefore, (1) the NO_3^- in precipitation was probably due to the oxidation of unmeasured gaseous NO_3, HNO_3, N_2O_5, and organic nitrogen compounds in the troposphere and/or the washout of particulate NO_3^- and HNO_3, and (2) the $[NO_2]$ reductions were probably due to vertical convection within the storm system of the locally-produced NO_2 from the surface to the free troposphere.

Precipitation did not significantly influence the daily mean $[O_3]$. This would be expected, if the mean daily O_3 was a result of advection and not local production. Some evidence exists to indicate that high levels (above mean ambient regional levels) O_3 represent locally produced O_3, with some reductions in $[O_3]$ probably also due to vertical convection of the gas within the storm system from the surface to the free troposphere.

Evidence tends to support the hypothesis that the precipitation acts to 'cleanse' the atmosphere of NO_2 for at least a short time through the physical process of vertical convection of elevated concentrations of pollutants from lower troposphere to the free troposphre. There is, however, no evidence that the precipitation NO_3^- is directly related to the chemical oxidation of ambient $[NO_2]$. Trends and tendencies found in this study may be significant when the time of storm precipitation is taken into account and shorter term mean concentrations are considered to establish influences of the precipitation. Additional work also needs to be done to determine the other nitrogenous compounds (HNO_3, PAN, and others) in the atmosphere over Vincennes, and their relationship to the nitrate ion content of the precipitation.

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SOIL AND PLANT ANALYSES RESEARCH IN SAHELIAN WEST AFRICA

H.W. Ohm, R.L. Rhykerd, and C.L. Rhykerd
Department of Agronomy
Purdue University
West Lafayette, Indiana 47907

INTRODUCTION

The Sahelian zone of West Africa suffers from a very low level of food production. Low and variable annual rainfall (250-750 mm) during a 60- to 120-day rainy season is generally assumed to be the reason for the low food production. However, another major constraint to increasing food production in this region is the improverished soil characterized by low soil pH, organic matter (O.M.), fertility, and cation exchange capacity (Jones and Wild, 1975; Ohm and Nagy, 1985). Extremely variable plant growth usually is associated with these soils.

In 1979, Purdue University initiated a USAID supported farming systems project in Burkina Faso (then Upper Volta) to develop technology for increasing food production in this region of West Africa. As this farming systems project progressed, it became apparent that very little data existed in this region, concerning the mineral nutritional status of soils and plants. Thus, in 1984, a study was initiated to analyze some of the soils and cereal plants involved in the farming systems project to identify mineral deficiencies.

The major objective of this investigation was to analyze cereal crop plants and associated soils from the Sahel Region of Burkina Faso for the primary purpose of determining the mineral nutritional status of these crops. There is a great need for these data particularly in Burkina Faso.

MATERIALS AND METHODS

Soil and plant samples were collected during the 1984 growing season from farmer-managed experiments at five locations in Burkina Faso, which were a part of an USAID funded Farming Systems Project. The five locations were selected on the basis of soil type and geographic distribution. Corn, sorghum, and millet leaves were obtained, when the plants were near anthesis, dried, and sent along with soil samples to the Purdue Soil Testing Laboratory.

Plant mineral analysis was conducted by means of an emission spectrograph. Soil samples were analyzed for organic matter, pH, extractable P (Bray P_1), exchangeable K, Ca, and Mg, cation exchange capacity (CEC), and percent base saturation according to procedures outlined by Dahnke (1988). Sulfur analysis of soil samples was conducted at the University of Wisconsin Soil Testing Laboratory.

RESULTS AND DISCUSSION

Mineral composition of plants. Table 1 shows the ranges from low to high among the cereal leaf samples from the five locations in Burkina Faso. In order for these data to be meaingful, it is necessary to compare them with known critical

TABLE 1. Ranges in mineral composition of corn, sorghum, and millet leaves sampled at anthesis on five farmer-managed experiments in Burkina Faso, 1984. Critical concentration values for corn ear-leaves at tasseling are presented for comparison.

	Corn Ear-leaf*	Cereal		
Element	Critical Values	Corn	Sorghum	Millet
	%		Range in Percent	
N	3.00	2.01-4.23	1.25-4.48	1.20-4.21
P	0.25	0.12-0.32	0.10-0.35	0.10-0.30
K	1.90	1.59-3.84	1.20-3.70	1.84-3.51
Ca	0.40	0.21-0.53	0.17-0.68	0.20-0.83
Mg	0.25	0.12-0.35	0.08-0.36	0.06-0.32
S	0.20	0.14-0.28	0.09-0.30	0.09-0.25
	mg/kg		Range in mg/kg	
Mn	15	29-123	22-126	35-78
Fe	25	108-286	110-339	109-373
B	10	4-16	3-10	2-12
Cu	5	6-13	4-14	5-17
Zn	15	21-52	22-86	16-45
Al	—	100-768	149-788	195-875
Na	—	13-82	7-76	25-115

* Melsted, *et al.*, 1967.

TABLE 2. Ranges in soil test values of soil samples taken from five farmer-managed experiments in Burkia Faso, 1984.

Analysis	Range*
Soil pH	5.0-8.0
P, ppm	0.5-120
K, ppm	45-499
O.M., %	0.29-4.05
Ca, ppm	140-3,000
Mg, ppm	36-530
S, ppm	0.5-16.5
CEC, meg/100 g	1-14
Base Sat., %	34.2-96.1

* A total of 141 soil samples.

values for these nutrient elements. Critical values for corn leaves at tasseling for the United States are also presented in Table 1 (Melsted, *et al.*, 1967). These comparisons reveal that deficiencies exist for all nutrient elements in the investigation except Mn, Fe, and Zn. No critical values are presented for Al and Na as these are not essential elements for plants.

The lowest leaf concentration of N is 1.20%, which is extremely deficient. However, this is not surprising, when one considers that a soil organic matter content (the principal source of N) as low as 0.29% was observed in this study (Table 2). Also, low rates of nitrogen fertilizer and/or animal manure are traditionally applied by farmers in Burkina Faso. It is interesting to note that some high N concentrations were also observed, with the highest value being 4.48. Soil organic matter content in excess of 4% (Table 2) was also found in this study.

The low P values in leaves were not unexpected, as most soils in this region are known to be low in P. It is a common practice for farmers of this region to apply P fertilizer or animal manure in order to alleviate P deficiencies.

Table 1 shows the ranges in mineral composition found in corn, sorghum, and millet leaves. In general, the mineral concentrations in corn tend to be the highest, and millet mineral concentrations tend to be the lowest. This is to be anticipated because corn is less tolerant of low fertility soils than millet and sorghum. Consequently, farmers in this region grow corn only on the most fertile soils, and millet is relegated to the least fertile soils.

Soil analyses. The extremes in values of the various soil analyses are presented in Table 2. Although soil pH ranged from 5.0 to 8.0, most soils tend to be acid. Some soils tested very low in P, which is not uncommon for unfertilized soils of this region.

The lowest K soil test was 45 ppm exchangeable K and indicates a low K level using a standard for the Cornbelt. However, soil and plant analyses for K would indicate that it is not one of the most limiting nutrient elements, especially at the low yield levels common to the Sahel Region. The extremely high K soil test of 499 ppm exchangeable K is from a corn plot adjacent to a housing unit and indicates the use of "night soil," especially the urine fraction.

Soil organic matter content as low as 0.29% is a result of the very hot, dry climate and the resulting low total plant yields, along with a crop utilization program which often results in the removal of all, or nearly all, of the organic matter produced by the cereal crops.

Wide variations were found in exchangeable Ca and Mg values. The lowest Mg soil test of 36 ppm indicates a low level of Mg in the soil as values below 50 ppm are considered low. These low levels of exchangeable Ca and Mg are reflected in very low concentrations of Ca and Mg in the cereal leaves obtained from these plots (Table 1).

The wide range is S soil tests reflects the organic matter content of the soil, since S, as with N, in the soil is contained primarily in organic matter.

All CEC values tended to be low, ranging from 1 to 14 meg/100g. These values are not unexpected, since CEC is dependent upon the organic matter content as well as the type and content of clay.

The low base saturation values reflect the low levels of bases found in many of the soils of the Sahel Region.

SUMMARY

Soil and plant analyses from the Sahel Region of Burkina Faso strongly indicate that numerous mineral deficiencies exist in the commonly grown cereal crops. Lowest mineral levels were observed in millet plants, which are grown on the least fertile soils. Extremely low organic matter content and CEC would suggest very low levels of availability of various nutrients, especially N and S. Based on the results of this survey study, it is obvious that greater emphasis should be placed on the soil fertility aspect of agronomic experiments conducted in the Sahel Region.

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PERFORMANCE OF SWEET POTATO (*IPOMOEA BATATAS* L.) AS INFLUENCED BY CROP MIXTURE AND PLANT POPULATION DENSITY IN A TROPICAL FOREST ZONE

E. M. Ossom
Faculty of Agriculture
University of Science and Technology
P.M.B. 5080
Port Harcourt, Nigeria
and
C. L. Rhykerd
International Programs in Agriculture
Purdue University
West Lafayette, Indiana 47907

INTRODUCTION

Sweet potato *(Ipomoea batatas* L.) is a root crop more commonly grown in the savannah zones of Nigeria than in the forest zones. In recent years, efforts have been made to introduce this crop into the forested southern parts of Nigeria, where cassava (*Manihot esculenta* Crantz) is the staple root crop, and corn (*Zea mays* L.) is the major cereal crop. In the humid tropics, mixed cropping of cereals with low canopy crops which tend to control erosion and reduce soil temperature has a number of advantages (Norman, 1974). Cassava planted with two successive crops of sweet potato was lower than two successive cassava crops in net income and gross margin but relatively higher than two successive cassava crops in family income (CATIE, 1978). In Nigeria, the economic value of sweet potato depends on its ability to contribute to total yield from the farm, to bring about a sugary taste in foods, and to help in weed control. The effect of intercropping with corn or cassava on tuber yield, leaf size, petiole length, and weed control ability in sweet potato is discussed in this paper.

MATERIALS AND METHODS

Two experiments were conducted in the 1985/86 and 1987/88 rainy seasons on a sandy loam (typic paleudult) soil at the Research and Teaching Farm of the University of Science and Technology, Port Harcourt (4°46′N, 7°01′ E). The initial fertility of the soil was as follows: pH in water, 5.43; N, 600 ppm; P, 33.0 ppm (measured by the Bray and Kurtz No. 1 method); and exchangeable K, 35.9 ppm.

Experiment 1. Monocrop and intercrop populations of sweet potato, cassava, and corn were sown simultaneously on 25 April 1985. The variety of sweet potato grown was "TIS 146/3092", obtained from the National Root Crops Research Institute, Umudike, Nigeria. The corn and cassava varieties used were "FARZ 34" and "30211", respectively. The experimental design was a randomized complete block (RCB) with four replications in plots 4 m × 6 m with a 0.5 m space between plots and a 1 m space between replicates. Treatments (T) in experiment 1 were: T_1, monocropped corn (70 cm × 100 cm); T_2, monocropped sweet potato

(100 cm × 100 cm); T_3, monocropped cassava (100 cm × 100 cm); T_4, corn (70 cm × 100 cm) + cassava (100 cm × 100 cm); T_5, corn (70 cm × 100 cm) + cassava (100 cm × 100 cm); T_6, sweet potato (100 cm × 100 cm) + cassava (100 cm × 100 cm); and T_7, corn (70 cm × 100 cm) + cassava (100 cm × 100 cm) + sweet potato (100 cm × 100 cm). Cassava and sweet potato were planted at the top of the ridge, while corn was planted on one side of the ridge. Corn was sown at the rate of three kernels per hill. Two weeks after planting (WAP), the crop was thinned to two plants per hill, giving a population of about 30,000 plants/ha in both pure and mixed stands. Cassava and sweet potato were planted at the same time, using one stem cutting/stand in each case.

NPK (15:15:15) was applied to the monocrops at the following rates: corn only, 150 kg/ha at 4 WAP followed by 50 kg/ha at 10% flowering; sweet potato only, 400 kg/ha at 4 WAP; cassava only, 200 kg/ha at 4 WAP and another 200 kg/ha at 20 WAP. For the intercrops, the following rates were used: corn + sweet potato, 150 kg/ha at 4 WAP followed by 150 kg/ha at 10% corn flowering; corn + cassava, 150 kg/ha at WAP and repeated at 10% flowering; sweet potato + cassava, 400 kg/ha at 4 WAP; corn + cassava + sweet potato, 150 kg/ha at 4 WAP followed by 50 kg/ha at 10% corn flowering. No fertilizer was applied to any treatment at planting, in keeping with local farming practices. The crops were harvested after the following periods: corn, 16 WAP; sweet potato, 24 WAP; and cassava, 54 WAP. At each harvest, gross plot yields were taken. For both cassava and sweet potato, only tubers were harvested and weighed, whereas for corn, only grain-weight was considered at 15.5% moisture content.

Weed infestation in plots was estimated by means of a 100 cm × 100 cm quadrat at 24 WAP to enable the effective weed suppression ability of the sweet potato to be evaluated just before its harvest. Four random samples/plot were taken. To estimate weed infestation, a scale of 0 to 5 was used. On this scale, 0 (zero weeds in the quadrat) represented the minimum weed density, while 5 (entire ground space covered by weeds) represented the maximum weed density. This method had been used before by Ossom (1986) and Orluchukwu and Ossom (1988). Leaf area measurements were made on sweet potato at harvest. Thirty fresh leaves/plot were randomly obtained from harvested vines. The leaves were laid flat on paper and their outlines were traced. A transparent centimeter grid was superimposed on the traced outlines, and the area/leaf was measured to obtain the average leaf size. Francis, *et al.* (1969) had suggested using of 5-10 leaves in one replicate. The same method was used by Ramanujam and Indira (1978), who found it to be in agreement with planimeter readings. In this experiment, the average leaf size was the average of the thirty randomly picked leaves/plot. Linear measurements were used in determining petiole lengths.

Experiment 2. Based on the observations in experiment 1, experiment 2 was designed to investigate the performance and compatibility of sweet potato in a sweet potato-cassava association with a fixed cassava population density but with a varying sweet potato population density. The relationship between the two tuber crops was more closely monitored in the absence of the cereal crop. The crops were planted on April 7, 1987, after the start of the rainy season. Experiment 2 consisted of seven treatments in an RCB design replicated 4 times. Treatments were as follows: T_1, sweet potato only at 25 cm × 100 cm; T_2, sweet potato only at 50 cm × 100 cm; T_3, sweet potato only at 100 cm × 100 cm; T_4, sweet potato (25 cm × 100 cm) + cassava (100 cm × 100 cm); T_5, sweet potato (50 cm × 100 cm) +

TABLE 1. Influence of crop mixture on the yield of sweet potato, 1985-1986.

Crop Mixture	Number of Plants/ha			Single Crop Yield/Yr (mt/ha)			Total Yield/Yr (mt/ha)
	Sweet Potato	Cassava	Corn	Sweet Potato	Cassava	Corn	
Corn	0	0	30,000	0	0	2.46	2.46
Sweet Potato	10,000	0	0	5.66	0	0	5.66
Cassava	0	10,000	0	0	8.33	0	8.33
Corn + Sweet Potato	10,000	0	30,000	1.38	0	1.88	3.26
Corn + Cassava	0	10,000	30,000	0	4.48	1.96	6.44
Sweet Potato + Cassava	10,000	10,000	0	2.85	4.29	0	7.14
Corn + Cassava + Sweet Potato	10,000	10,000	30,000	1.41	4.06	1.63	7.10
L S D	—	—	—	0.51	0.34	0.51	2.91

Values are means of 4 replications.

TABLE 2. Effect of crop density on performance of sweet potato, 1987-1988.

Crop Combination	Population/ha		Petiole Length (cm)		Leaf Size (cm_2)		Weed Score (0-5)	Single Crop Yield (mt/ha)		Total Crop Yield/Year (mt/ha)
	Sweet Potato	Cassava	Sweet Potato	Cassava	Sweet Potato	Cassava		Sweet Potato	Cassava	
Sweet Potato	40,000	0	16.40	0.0	64.00	0.0	0.0	1.33	0.0	1.33
Sweet Potato	20,000	0	14.70	0.0	52.60	0.0	1.30	1.37	0.0	1.37
Sweet Potato	10,00	0	16.60	0.0	69.90	0.0	1.90	1.18	0.0	1.18
Sweet Potato + Cassava	40,000	10,000	13.13	16.56	55.00	n.a.	2.50	0.58	17.42	18.00
Sweet Potato + Cassava	20,000	10,000	15.05	18.88	67.70	n.a.	4.00	0.88	9.08	9.96
Sweet Potato + Cassava	10,000	10,000	14.80	14.52	63.50	n.a.	4.50	0.48	23.25	23.73
Cassava only	0	10,000	0.0	17.14	0.0	n.a.	4.80	0.0	20.42	20.42

Values are means of 4 replications.
n.a. = data not available.

TABLE 3. Influence of sweet potato density on weed suppression in mixed cropping.

Cropping System (with density)	Name of Weed	Sub-Class	Relative Abundance (%)	Weed Score (0-5)
Sweet Potato (40,000 plants/ha)	(No Weeds)	—	0	0
Sweet Potato (20,000 plants/ha)	*Talinum triangulare* Jacq.	Dicot	95)	1.3
	Corchorus olitorius L.	Dicot	5)	
Sweet Potato (10,000 plants/ha)	*Ipomoea involucrata* Beauv.	Dicot	60)	1.9
	Calopogoniun mucunoides Desv.	Dicot	40)	

Sweet Potato (40,000 plants/ha)	*Aspilia africana* (Pers.) C.D.	Dicot	5)	
	Ipomoea involucrata Beauv.	Dicot	75)	
			)	2.5
+ Cassava (10,000 plants/ha)	*Amaranthus spinosus* L.	Dicot	3)	
	Commelina nudiflora L.	Moncot	17)	
Sweet Potato (20,000 plants/ha)	*Ipomoea involucrata* Beauv.	Dicot	50)	
	Centrosema pubescence Benth	Dicot	20)	
			)	4.0
+ Cassava (10,000 plants/ha)	*Aspilia africana* (Pers.). C.D.	Dicot	15)	
	Triumfetta rhomboidea L.	Dicot	15)	
Sweet Potato (10,000 plants/ha)	*Commelina nudiflora* L.	Monocot	15)	
	Digitaria horizontalis Willd.	Monocot	30)	
			)	
+ Cassava (10,000 plants/ha)	*Ageratum conyzoides* L.	Dicot	25)	
	Talinum triangulare Jacq.	Dicot	18)	4.5
			)	
	Centrosema pubescence Benth.	Dicot	10)	
	Hibiscus meeusual Excell.	Dicot	2)	
Cassava (10,000 plants/ha)	*Aspilia africana* (Pers.) D.C.	Dicot	65)	
	Triumfetta rhomboidea L.	Dicot	15)	
	Amaranthus viridis L.	Dicot	5)	
	Ageratum conyzoides L.	Dicot	5)	
			)	4.8
	Digitaria horizontalis Willd.	Monocot	5)	
	Commelina nudiflora L.	Moncot	3)	
	Panicum maximum L.	Monocot	2)	

Values are means of 4 replications.

cassava (100 cm × 100 cm); T_6, sweet potato (100 cm × 100 cm) + cassava (100 cm × 100 cm); and T_7, cassava only at 100 cm × 100 cm. Fertilizer rates consisted of 400 kg/ha of NPK (15:15:15) applied at 4 WAP to sweet potato, while monocropped cassava received 200 ka/ha at 4 WAP and at 20 WAP (Ethirveerasingam, *et al.*, 1985). All intercropping mixtures received 400 kg/ha of NPK at 4 WAP. Weed infestation, leaf size, and petiole measurements were made as described in Experiment 1.

RESULTS: EXPERIMENT 1, 1985-86

Fresh weight yield. Results of this experiment suggested that sweet potato was more compatible (than corn) with cassava in intercropping. While sweet potato alone yielded 5.66 mt/ha in mixture, it yielded 1.38 mt/ha, when grown in association with corn, 2.85 mt/ha, when grown with cassava, and 1.41 mt/ha, when intercropped with both cassava and corn (Table 1). Highest total tuber yield per land area among the mixed crops was obtained, when sweet potato was grown together with cassava. The lowest yield (kernel + tuber) per land area was obtained, when corn was intercropped with sweet potato. Cassava tuber yields were depressed, when intercropped with sweet potato alone and were further reduced, when all three crops (corn, sweet potato, and cassava) were grown together. These results were in agreement with earlier results obtained in sweet potato intercropping studies with cassava and other crops (Soria, 1976; CATIE, 1978). Reduction in cassava tuber yield, when all crops were sown together, was also in agreement with findings of Ossom (1976), who observed that the larger the number of crops in a mixed cropping system, the greater the competition among component crops.

Leaf size. The area/leaf of monocropped sweet potato was the highest (63.15 cm^2). Among mixed crops, sweet potato grown in association with corn had the highest area/leaf (59.45 cm^2), while that grown with cassava was the lowest (58.36 cm^2). However, these differences were not statistically significant. There was a positive linear correlation ($r = 0.88$) between area/leaf and tuber yield, which was significant at $P = 0.05$.

Petiole length. The petiole length of sweet potato was greatest (20.10 cm), when the crop was planted with cassava. Petiole length was shortest (16.90 cm), when grown in association with both corn and cassava. There was a positive, nonsignificant correlation ($r = 0.63$) between petiole length and tuber yield. Petiole length plays an important role in leaf display for efficient photosynthesis, and it is likely that any factors which cause stress may also adversely influence petiole length as well as leaf area. The interspecies competition among crops in this experiment was apparently responsible for decreased petiole length in sweet potato.

RESULTS: EXPERIMENT 2, 1987-88

Fresh weight yield. Table 2 shows the effect of crop density on the performance of sweet potato. Total tuber yield per land area was greatest, when sweet potato was intercropped with cassava at a population of 10,000 plants/ha for each crop in the mixture. There was a reduction in cassava yield, when intercropped with sweet potato, as was also observed in Experiment 1. These results agreed with those of CATIE (1978), which observed that a reduction in cassava yields resulted from competition with sweet potato. The yield of sweet potato in

TABLE 4. Monthly rainfall (mm) in the years when the sweet potato was grown.

Period		Rainfall	Period		Rainfall	Period		Rainfall	Period		Rainfall
Jan.	1985	17.2	Jan.	1986	50.7	Jan.	1987	8.4	Jan.	1988	16.1
Feb.	1985	6.0	Feb.	1986	71.5	Feb.	1987	85.4	Feb.	1988	52.3
March	1985	82.9	March	1986	71.5	March	1987	192.9	March	1988	118.5
April	1985	256.3	April	1986	224.0	April	1987	72.5	April	1988	186.0
May	1985	390.8	May	1986	240.3	May	1987	234.5	May	1988	232.7
June	1985	282.0	June	1986	171.0	June	1987	269.4	June	1988	203.5
July	1985	265.1	July	1986	371.5	July	1987	477.3	July	1988	258.8
August	1985	348.0	August	1986	257.9	August	1987	427.5	August	1988	319.8
Sept.	1985	278.9	Sept.	1986	286.1	Sept.	1987	189.6	Sept.	1988	397.9
Oct.	1985	153.7	Oct.	1986	184.0	Oct.	1987	189.6	Oct.	1988	258.9
Nov.	1985	61.8	Nov.	1986	161.2	Nov.	1987	50.2	Nov.	1988	106.8
Dec.	1985	0.0	Dec.	1986	0.0	Dec.	1987	4.2	Dec.	1988	30.2
Totals		2232.7			2199.4			2201.5			2181.5

mixture was lower than in monocrop, but there was an increase in total crop yield obtained per unit of land under intercropping. This result agreed with the criteria of Willey (1979) for assessing yield advantages in intercropping. There was a highly significant ($P = 0.01$) correlation ($r = 0.99$) between number of sweet potato tubers/plot and tuber yield/plot. These results indicate the need for a reasonably high total population, a conclusion which had also been reached by other workers (IRRI, 1974; Kassam, 1973).

Leaf size. As shown in Table 2, area/leaf of monocropped sweet potato at 10,000 plants/ha was greatest, while that at 20,000 plants/ha was lowest. Intercropping resulted in reduced area/leaf of the crop, as had been observed by Ossom (1976). The degree of reduction appeared to be proportional to the total number of plants/plot. No relationship was found between area/leaf and tuber yield ($r = 0.01$). For a tuber crop, there should be a correlation between leaf area and tuber yield, if pests and diseases do not reduce leaf size and photosynthetic efficiency. It is unlikely that the attack on sweet potato leaves by sweet potato weevil (*Cylas puncticollis*) and sweet potato butterfly (*Acraea acerata*) during this experiment interfered with the leaf area development of the plant.

Petiole length. When planted as a monocrop at 40,000 plants/ha, sweet potato had an average petiole length of 16.40 cm, whereas when intercropped (40,000 plants/ha of sweet potato and 10,000 plants/ha of cassava), petiole length was reduced to 13.13 cm. The correlation between petiole length and tuber yield was low ($r = 0.21$) and not significant, indicating that petiole length may not contribute much to tuber yield. Cassava had the lowest petiole length, when intercropped with sweet potato (10,000 plants/ha for each crop species), whereas monocropped cassava had a petiole length of 17.14 cm (Table 2). As in Experiment 1, intercropping resulted in reduced petiole length of sweet potato, but this reduction was more noticeable, when the crop was interplanted at 10,000 and 40,000 plants/ha through cassava at 10,000 plants/ha. This seems to indicate that interspecies competition may have a greater influence than intraspecies competition in reduction of petiole length.

Weed infestation. The influence of plant density on weed suppression is shown in Table 3. Broadleaf weeds infested all plots more than grassy weeds. Sweet potato at 40,000 plants/ha suppressed weeds most effectively, while monocropped cassava had the lowest weed suppression. Among mixed crops, sweet potato at 40,000 plants/ha + cassava at 10,000 plants/ha gave the best weed suppression. Light is one of the factors affecting weed-crop balance. Results from this study confirm earlier findings (Shetty, *et al.*, 1982) that the differential shading ability of a crop canopy was one of the factors which determined crop-weed competition balance and thus contributed to the differential crop productivity observed in intercropping systems. Leihner (1983) observed that one of the advantages of intercropping is better soil coverage obtained from the beginning with the association. Such a coverage diminishes light penetration to the soil and reduces weed growth. Peasant farmers do not usually keep their farms completely weed-free as at experimental stations. Rather, they intercrop as a form of weed control and remove those weeds they know to be aggressive. A judicious choice of crop combination and plant population density can help the small farmer in cultural weed control.

CONCLUSIONS

Sweet potato is compatible with cassava in intercropping. Increased total yield and effective weed control are the two major advantages derived from the use of sweet potato in intercropping at a suitable crop density. The lower yields of sweet potato in Experiment 2 may have resulted from reduced rainfall and its poor distribution, particularly during the growing period of April to October (Table 4). The sweet potato appeared to be at a disadvantage, while cassava seemed to have benefitted from intercropping. Also, the amount of rainfall during the three months prior to planting favored a better soil moisture condition for sweet potato in Experiment 1 than in Experiment 2 (Purseglove, 1977). Sweet potato is not adapted to this locality (cassava is), but research efforts are continuing in the identification of cultivars and varieties which are promising in their performance. The results of this work indicate that the density at which sweet potato quickly covers the soil would make an important contribution to tuber yield and cultural weed control for the peasant farmer, who often lacks capital to purchase agricultural chemicals.

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USING ARTIFICIAL INTELLIGENCE TO PROPERLY ESTABLISH ALFALFA

R.L. Rhykerd, C.L. Rhykerd, Jr., D.D. Jones, and C.L. Rhykerd
Departments of Agronomy and Agricultural Engineering
Purdue University
West Lafayette, Indiana 47907

INTRODUCTION

Artificial intelligence, as we know it today, had its beginning only about 3 decades ago. In the 1970s, artificial intelligence research began to focus on applying techniques to more specific subject areas and developing programs containing specific knowledge about a certain problem. This led to the development of expert systems (Stock, 1987; Jones, *et al.*, 1987). Agriculturally related expert systems are now being developed to help production managers make agriculture more efficient and profitable.

EXPERT SYSTEMS

An expert system is a written program, usually computerized, that emulates the decision-making process of a human expert. It allows a non-expert to reach the conclusion that would normally require consultation with an expert. An expert system tells the user how the recommendation or conclusion was reached and can further explain the question on the computer screen or on a print-out.

An expert system is developed for a specific, well-defined problem and uses an expert's knowledge and experiences to create a knowledge base. An advantage of expert systems over many conventional programming techniques is the ability to integrate subjective (heuristic), objective (factual), and incomplete or uncertain information that is used by the human expert.

In artificial intelligence parlance, the three major components in the development of an expert system are the domain expert, the knowledge engineer, and the development tool. The domain expert is the person who is the source of the expertise built into the knowledge base. The knowledge engineer extracts the knowledge from the human expert and translates it into a computer program. Lack of well-trained knowledge engineers has restricted the application of expert systems to agricultural problems. The development tool (shell) is simply a stripped-down expert system. Knowledge engineers build expert systems by adding a domain specific knowledge base to the shell.

DEVELOPING THE ALFALFA EXPERT SYSTEM

In this study, a rule-based expert system was developed which enables an alfalfa grower to produce higher yielding alfalfa. In developing this expert system, C.L. Rhykerd served as the domain expert and R.L. Rhykerd and C.L. Rhykerd, Jr. as knowledge engineers with assistance from D.D. Jones. In this study, PC Plus, an expert system shell from Texas Instruments, Inc., was used to develop the program by adding the knowledge base for maximizing alfalfa production.

The "knowledge engineering" process or stages involved in the development of an expert system are acquiring, formalizing, implementing, and verifying the knowledge required to develop the program. These stages have been discussed by numerous authors (Jones, *et al.*, 1987; Rhykerd, *et al.*, 1988; Stock, 1987).

The objective of this study was to develop an expert system that models the procedures used by a forage specialist in determining agronomic recommendations for profitable alfalfa production. This alfalfa expert system includes the following management decisions for successfully establishing a productive stand of alfalfa.

Further decisions on use of insecticides, harvest times, hay curing, or forage chopping, etc., remain to be added.

Soil pH. Generally, since alfalfa is very sensitive to soil acidity, the first management decision that must be made when considering the seeding of alfalfa, is lime requirement based on soil pH. Therefore, the first question posed by this expert system is, "Is the soil pH 6.6 or above?" If the response is "Yes", then the computer operator can proceed to the next management decision. If the response is "No", then the recommendation is to apply lime to raise the soil pH to 6.6.

Soil fertility. The second management decision built into the expert system concerns the P and K levels of the soil in the field to be seeded to alfalfa. Soil test results are required, to compare with those presented on the screen, indicating what the levels of P and K should be for a high soil test level.

Soil drainage. A well-drained soil is essential for the successful establishment and long-term maintenance of a productive stand of alfalfa. Therefore, the third management decision asks the computer operator whether the soil is well-drained, moderately well-drained, or poorly drained. The best alternative is well-drained, and the computer operator can proceed to the next decision. If the soil is moderately well-drained, then a phytophthora resistant variety is recommended, since phytophthora root rot is the primary reason for loss of alfalfa stands on wet soils. If soil drainage is categorized as poorly drained, the expert system will recommend that the farmer not seed alfalfa on that soil.

Chemical weed control. Alfalfa growers now have the option of applying herbicides when seeding alfalfa rather than relying on a small grain companion (nurse) crop to help control weeds. However, the decision as to which herbicide should be applied depends upon whether the farmer is seeding pure alfalfa or an alfalfa-grass mixture, since several of the herbicides kill grasses. Therefore, the first question posed by the expert system relative to chemical weed control is whether the seeding is pure alfalfa or an alfalfa-grass mixture.

Expected longevity of stand. Most alfalfa producers prefer to leave a stand for a period of 3 to 5 years, due to high establishment costs. However, it is not uncommon for a farmer to want only a two-year stand or possibly one season. Consequently, the expert system will ask the computer operator how long the stand is to be left. If the response is more than two years, the expert system will recommend an anthracnose resistant variety, because anthracnose is a major cause of loss of alfalfa stands in Indiana on well-drained soils after two years. Bacterial wilt can also cause loss of stand after two years, but all alfalfa varieties sold today in Indiana are resistant to bacterial wilt. Variety recommendations also can be made for a variety to be used for green manure during just one growing season.

Variety recommendation. An expert system which can make variety recommendations to alfalfa growers has been developed previously (Rhykerd, *et al.*, 1988). The alfalfa variety selection expert system was used as a basis for this alfalfa management expert system, because it became apparent that successful alfalfa production is possible only when all management practices are followed—not just variety recommendation. It is not possible to make alfalfa variety recommendations without knowing the management considerations, i.e., the expected longevity of stand, soil drainage, and use of the crop. A major advantage of an alfalfa variety selection expert system is that a knowledge engineer can easily update, add, or delete varieties.

Method and rate of seeding. The final management decision to be made in this expert system concerns method and rate of seeding. Seedbed preparation and method of seeding are key factors, determining rate of seeding alfalfa. Consequently, this expert system asks the computer operator how the seedbed is to be prepared and the type of seeder to be used in the seeding operation. Due to the very small size of an alfalfa seed, depth of seeding and firmness of seedbed can determine rate of seeding. Seeding rate can be considerably reduced by preparing a seedbed that is fine textured on the surface and using a seeder that places the seed very shallow but lightly covers the seed and firms the soil over the seed.

SUMMARY

The complexity of modern alfalfa production technology necessitates consultation with a forage expert in order to produce profitable yields of alfalfa. Recent advances in the application of artificial intelligence through the development of expert systems enable farmers to use a computer program to reach conclusions that normally require consultation with a forage expert. The objective of this research was to develop an expert system that models the procedures used by a forage specialist in determining agronomic recommendations for profitable alfalfa production. This expert system makes the advice of a forage expert readily available to alfalfa producers, when making management decisions relative to liming, fertilization, drainage, weed control, longevity of stand, variety recommendation, and method and rate of seeding. This expert system is designed to be user-friendly and permits the farmer to by-pass those management practices that do not apply or for which he has no data. (e.g., soil test results).

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ACID RAIN TENDENCIES DURING MAY, JUNE, AND JULY 1988 IN WEST LAFAYETTE, INDIANA

Stephen J. Vavrus and John T. Snow
Department of Earth and Atmospheric Sciences
Purdue University
West Lafayette, Indiana 47907

ABSTRACT: Daily rainwater samples were collected from 29 April to 29 July 1988 at the Purdue University Agronomy Farm, six miles northwest of West Lafayette, Indiana. A total of 18 samples of 0.01 in. or more were collected; rainfall for the period was about 4.7 in., only 37% of normal. The average pH for the 18 samples was about 3.9, approximately 50 times more acidic than naturally-occurring rainfall. The average pH of 3.9 was lower (i.e., more acidic) than the 5-year average of about 4.2. Heavy rainfalls tended to be more acidic than light rainfalls, as the six heaviest rainfalls (pH = 3.9) were six times more acidic than the six lightest rainfalls (pH = 4.7). A strong correlation also existed between wind direction and acidity. Rainwater tended to be more acidic when the upper-air winds were from the south, southeast, or southwest prior to the rain event. These directions correspond to the regions of heavy coal burning by power plants in the Ohio Valley.

INTRODUCTION

Acid deposition has become an increasingly publicized issue in recent years. Extensive scientific and economic studies have been undertaken to examine the cause of acid deposition and the economic effects of proposed solutions. This study attempts to identify factors affecting the acidity of rainfall measured at one rural location in north-central Indiana during a three-month period in the spring and early summer of 1988.

In this study, only wet deposition, or "acid rain", was analyzed. As opposed to dry deposition, which involves deposition of sulfur and nitrogen oxide gases and particulates, wet deposition includes only those acid compounds deposited in liquid form (General Accounting Office, 1984). Sulfur dioxide (SO_2) and nitrogen oxides (NO and NO_2) are emitted by coal-fueled power plants, smelters, vehicles, and other sources. These emissions combine with water vapor in the air to create sulfurous and sulfuric acids (H_2SO_3 and H_2SO_4) as well as nitrous and nitric acids (HNO_2 and HNO_3). These acid compounds are then transported by upper-air winds and return to earth during rainfall. Naturally-occurring rainfall, i.e., rainfall without anthropogenic contaminants, is normally slightly acidic (hydrogen ion activity $[H+] = 2.51 \times 10^{-6}$ or, equivalently, $pH = 5.6$) due primarily to the creation of carbonic acid from the combination of carbon dioxide and water vapor (Liken, *et al.*, 1979). However, average annual pH values of 4.2 or less have become common this decade in the eastern half of the U.S. (Mohnen, 1988).

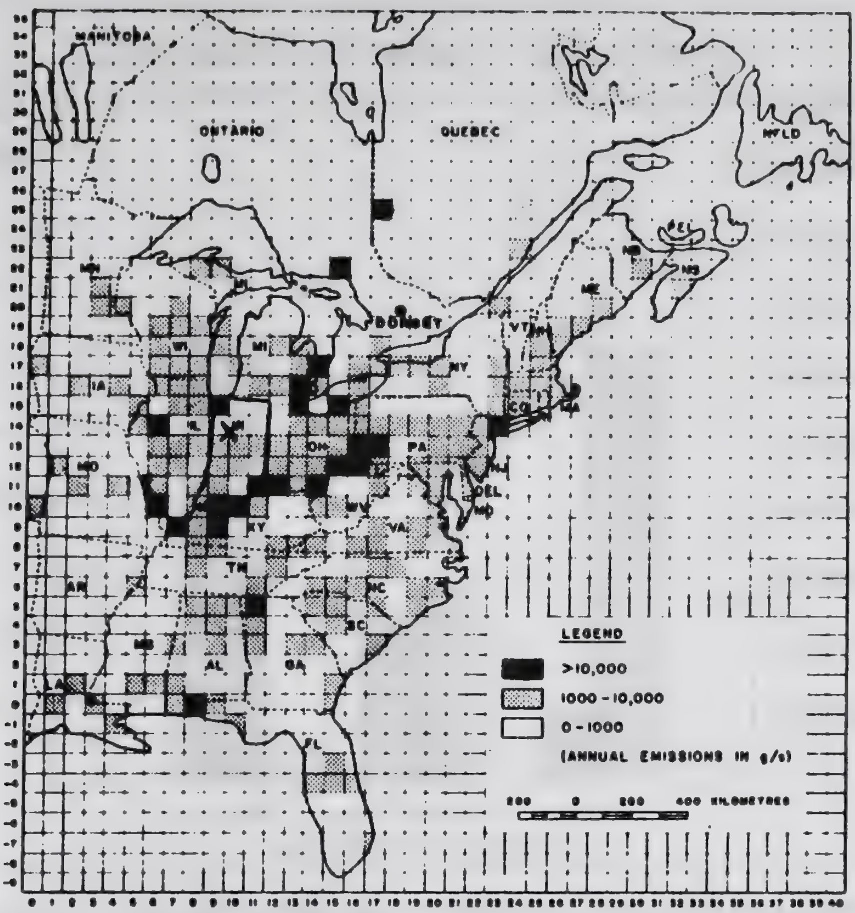
TABLE 1. Record of rainfalls (≥ 0.01 in.).

Date	Time (GMT)	Amount (in.)	[H+]	pH	Rate (in./hr.)
8 May	2030-2130	0.05	1.55×10^{-5}	4.81	0.05
9 May	0430-0630	0.24	6.61×10^{-5}	4.18	0.12
10 May	2115-2130	0.02	1.45×10^{-6}	5.84	0.04
13 May	2030-2230	0.20	1.15×10^{-4}	3.94	0.10
23 May	2000-2100 0400-0600 1300-1400	0.27	1.25×10^{-4}	3.90	0.07
24 May	2300-0000 0100-0300 0800-0900	0.20	6.46×10^{-5}	4.19	0.04
9 June	0100-0400	0.13	3.24×10^{-5}	4.49	0.04
29 June	1100-1400	0.05	7.24×10^{-6}	5.14	0.02
30 June	1600-2000	0.08	1.86×10^{-4}	3.73	0.02
11 July	1500-1600 1930-2130 2300-0000	1.10	3.80×10^{-4}	3.42	0.28
14 July	1430-1500	0.02	2.95×10^{-7}	6.53	0.04
17 July	2230-2245	0.01	1.15×10^{-6}	5.94	0.04
18 July	1200-1245	0.03	6.61×10^{-7}	6.18	0.04
19 July	1515-1615 2300-0200	1.98	3.31×10^{-5}	4.48	0.49
20 July	1100-1500	0.13	1.74×10^{-5}	4.76	0.03
21 July	1500-1930	0.04	6.76×10^{-5}	4.17	0.01
22 July	2030-2130	0.15	3.63×10^{-5}	4.44	0.15
25 July	1330-1500	0.03	6.03×10^{-5}	4.22	0.02

For this study, rainfall samples were collected from 29 April to 29 July 1988 at the Purdue University Agronomy Farm, located 6 miles northwest of West Lafayette, Indiana (at 40° 28′ N, 87° 00′ W; elevation = 705 ft.). The samples were collected using a Geochem Metrics Model 301 Automatic Sensing Wet/Dry Precipitation Collector, the same type of instrument which has been used by the National Atmospheric Deposition Program (NADP) at the Agronomy Farm for several years. This device positions a lid over the rain-collecting bucket when no rain is falling and so prevents alkaline material, such as calcareous dust, from entering the bucket and skewing results during long dry spells. Comparison of the catch in this collector with a nearby reference raingage (which also recorded the times each rain event began and ended) suggests that the collection efficiency of the Geochem Metrics Model 301 is no less than 80%.

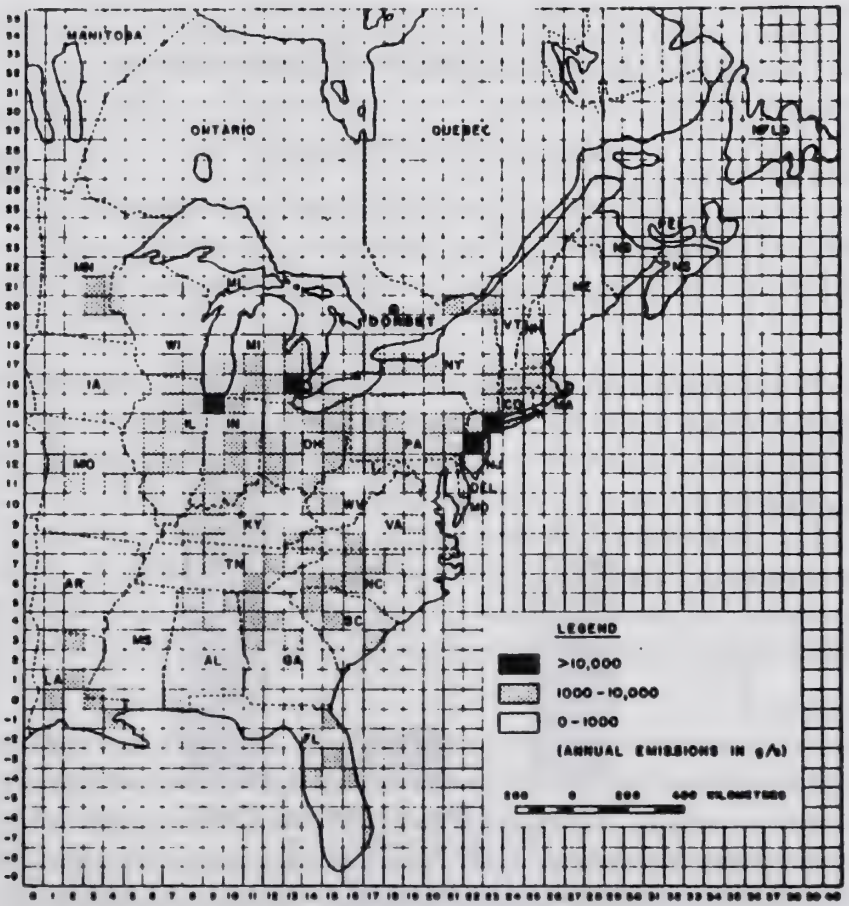
Samples were collected at 15Z each day and represent the total accumulation from rain event(s) during the previous 24 hours. Each sample was taken immediately to a laboratory in the Department of Agronomy on the main campus of Purdue University to determine its pH using a Fisher Accumet pH Meter Model 630. The equipment for the analysis was the same as that used by NADP. Comparison of the daily samples for 1988 with the corresponding NADP weekly sample taken at a nearby collector (of the same type as used here) indicated that no large difference in acidity resulted from use of the two different sampling intervals.

Wind patterns were analyzed to determine whether relationships exist between wind direction and acidity of associated rainfalls. In addition, NADP data



(A) Sulfur Dioxide (SO$_2$)

Source: U.S.A. emissions from SURE II data base.
Canadian emissions from Environment Canada.



(B) Nitrogen Oxides (NO$_x$)

Source: U.S.A. emissions from SURE II data base.
Canadian emissions from Environment Canada.

FIGURE 1. Source emission regions of sulfur dioxide and nitrogen oxides in eastern North America (after General Accounting Office, 1984).

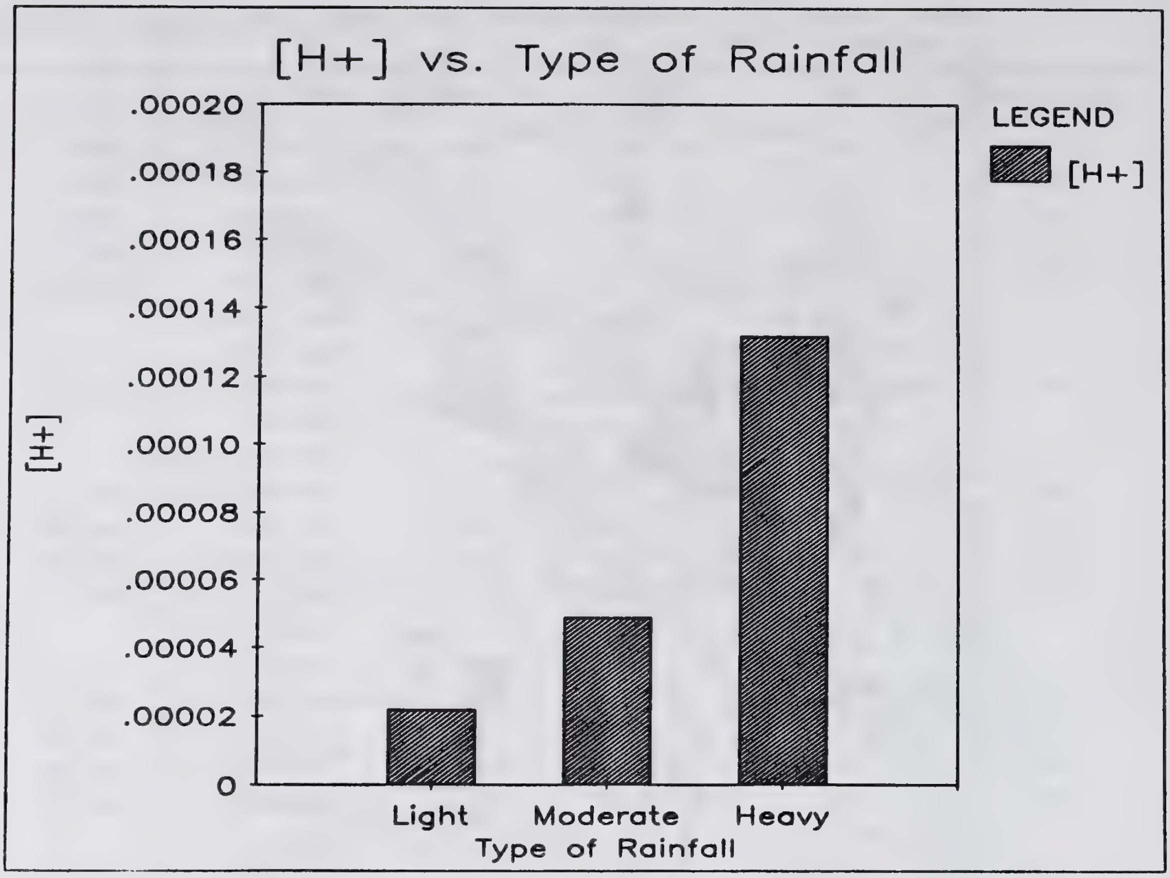


FIGURE 2. Variation in acidity according to amount of rainfall in an event.

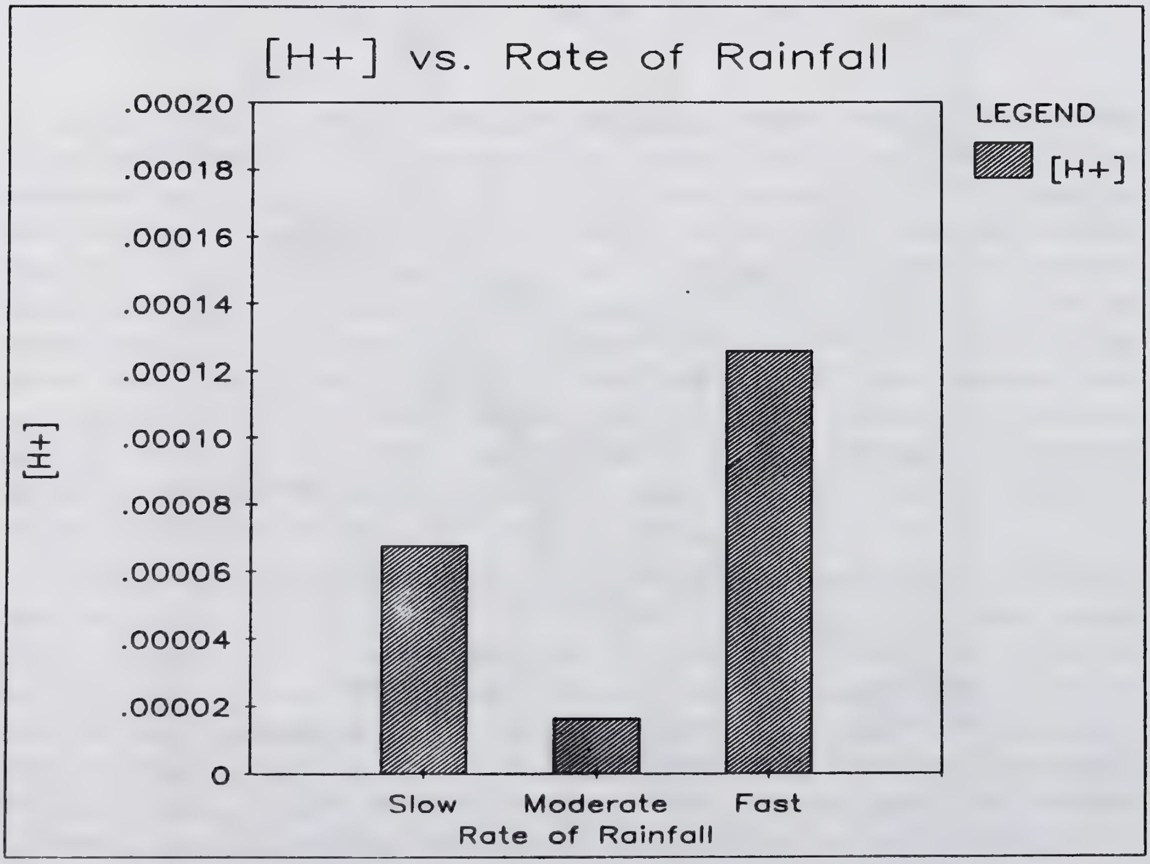


FIGURE 3. Variation in acidity according to rate of rainfall in an event.

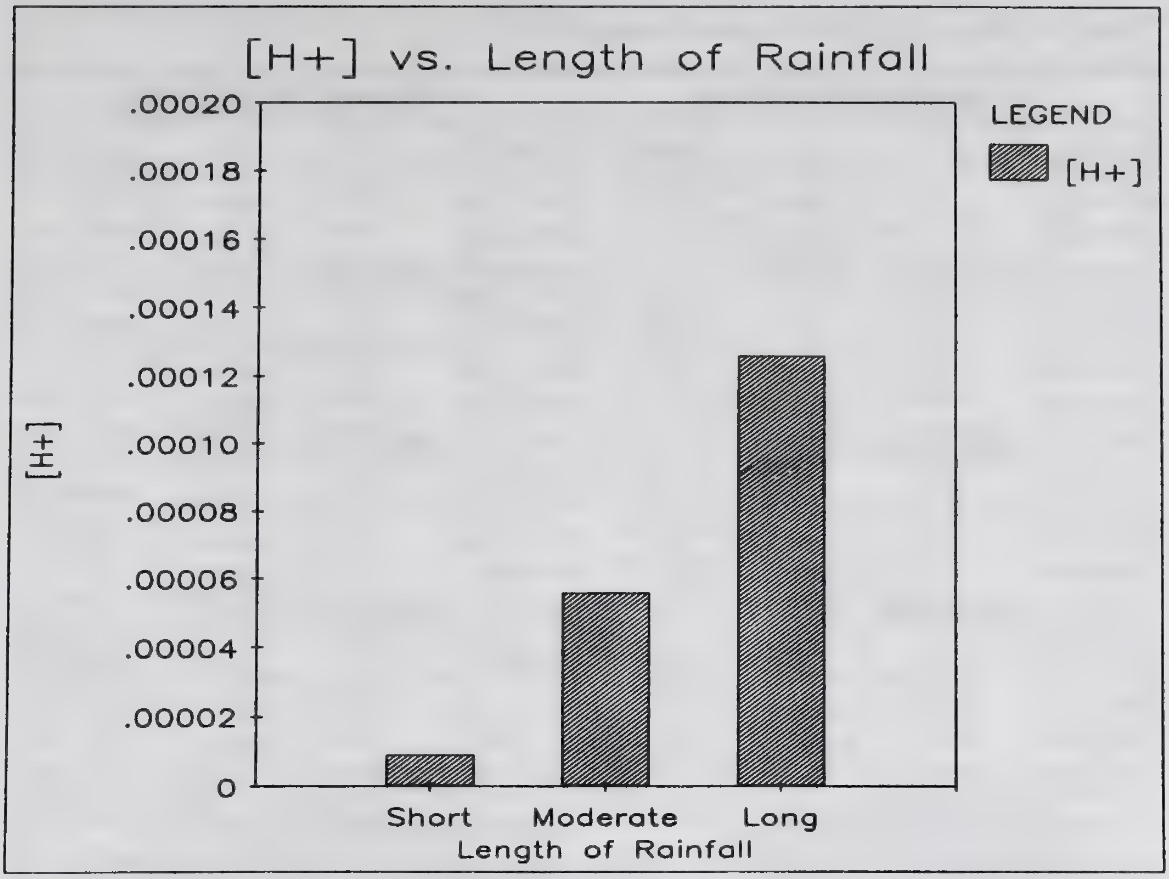


FIGURE 4. Variation in acidity according to length of rainfall in an event.

from the previous five years at the site were obtained and compared with data for this period in an effort to identify short term trends in rainfall acidity.

DATA AND ANALYSIS

Summary of rainwater samples. Samples from 18 rainfalls of 0.01 in. or more were obtained during the collection period. The date, time of production of each sample, rainfall amount, and pH are listed in Table 1. For use in later figures, hydrogen ion activity [H+] is also shown.

The average sample was 0.26 in. of rainwater with a pH of 3.9, about 50 times more acidic than naturally-occurring rainfall. (This is a weighted average and so is dominated by the two heavy rainfalls on 11 July and 19 July.) The most acidic rainfall occurred on 11 July (pH = 3.4), and the least acidic rainfall occurred on 14 July (pH = 6.5). Notice that the most acidic and least acidic samples for the entire collection period resulted from successive rain just 3 days apart, reflecting the high variability in acidity that occurred among events. The range of hydrogen ion activity from these two rainfalls represents about a 1300-fold difference in acidity.

Source regions. Figure 1 shows the distribution of sulfur dioxide and nitrogen oxide emissions in eastern North America. Recent studies indicate that in eastern North America sulfur dioxide is responsible for approximately two-thirds of the acidity in wet deposition, with nitrogen oxides contributing most of the remainder (General Accounting Office, 1984). Thus, sulfur dioxide appears to be the more important factor in wet deposition. Furthermore, a recent National

TABLE 2. Effect of wind direction on acidity.

24-48 Hours Before Rain			0-24 Hours Before Rain		
850 mb:	$[H^{\pm}]$	Events	850 mb:	$[H^{\pm}]$	Events
SW, S, SE:	9.33E-5	5	SW, S, SE:	1.12E-4	6
OTHERS :	4.79E-5	9	OTHERS :	4.47E-5	7
AMOUNT GREATER:	X 1.95		AMOUNT GREATER:	X 2.51	
700 mb:	$[H^{\pm}]$	Events	700 mb:	$[H^{\pm}]$	Events
SW, S, SE:	8.32E-5	6	SW, S, SE:	1.05E-4	7
OTHERS :	4.37E-5	9	OTHERS :	3.55E-5	7
AMOUNT GREATER:	X 1.90		AMOUNT GREATER:	X 2.96	
500 mb:	$[H^{\pm}]$	Events	500 mb:	$[H^{\pm}]$	Events
SW, S, SE:	1.20E-4	4	SW, S, SE:	1.41E-4	5
OTHERS :	3.72E-5	11	OTHERS :	3.09E-5	9
AMOUNT GREATER:	X 3.23		AMOUNT GREATER:	X 4.56	
300 mb:	$[H^{\pm}]$	Events	300 mb:	$[H^{\pm}]$	Events
SW, S, SE:	1.62E-4	3	SW, S, SE:	1.35E-4	5
OTHERS :	2.82E-5	10	OTHERS :	3.02E-5	8
AMOUNT GREATER:	X 5.74		AMOUNT GREATER:	X 4.47	
AVERAGE AMOUNT GREATER (ALL PRESSURE LEVELS): X 3.21			AVERAGE AMOUNT GREATER (ALL PRESSURE LEVELS): X 3.63		

Academy of Sciences report (1983) indicated that a linear relationship exists betwen the size of SO_2 emissions and the acidity of rainfall. Map A clearly shows that regions in southeastern Missouri, southwestern Illinois, and southern and eastern Indiana produce large amounts of SO_2 (Kurtz, *et al.*, 1984). These regions are located to the southwest, south, and southeast of the Purdue Agronomy Farm, respectively, and would be expected to contribute most heavily to wet deposition at this location, if wind strength and persistence were sufficient to transport acid compounds to the collection site. Within these southwest, south, and southeast sectors, the high SO_2-emission regions (black) are from 180 to 270 miles from the collection site. For acid compounds from these source regions to reach the collection site, winds need to average only 3-5 knots during the 48 hours prior to rainfall or 7-10 knots during the 24 hours prior to rainfall.

Horizontal transport. An analysis of wind directions and wind speeds occurring prior to each rainfall event was made at four levels in the atmosphere: 850 mb, 700 mb, 500 mb, and 300 mb. Wind data were not obtainable for one or more levels for each of the 18 rainfall events, so that the number of occurrences of wind analyzed at each level is less than the number of rainfall events.

The results presented in Table 2 show the effect of wind direction prior to a rain event on hydrogen ion activity in rainfall. Note particularly the differences in acidity associated with winds from the southwest (202.5°-247.5°), south (157.5°-202.5°), and southeast (112.5°-157.5°) as compared to winds from all other directions. The columns represent winds occurring between 24 to 48 hours before the rain event (48 hours before collection time) and winds up to 24 hours before the

TABLE 3. Effect of wind speed on acidity.

24-48 Hours Before Rain			**0-24 Hours Before Rain**		
850 mb:	$[H^{\pm}]$	Events	850 mb:	$[H^{\pm}]$	Events
< 10 KNOTS:	8.71E-5	8	< 10 KNOTS:	1.17E-4	6
> 10 KNOTS:	3.16E-5	6	> 10 KNOTS:	4.07E-5	7
AMOUNT GREATER:	X 2.75		AMOUNT GREATER:	X 2.87	
700 mb:	$[H^{\pm}]$	Events	700 mb:	$[H^{\pm}]$	Events
< 15 KNOTS:	7.94E-5	9	< 15 KNOTS:	5.89E-5	6
> 15 KNOTS:	2.88E-5	6	> 15 KNOTS:	7.94E-5	8
AMOUNT GREATER:	X 2.76		AMOUNT GREATER:	X .74	
500 mb:	$[H^{\pm}]$	Events	500 mb:	$[H^{\pm}]$	Events
< 20 KNOTS:	1.00E-4	7	< 20 KNOTS:	1.05E-4	6
> 20 KNOTS:	2.40E-5	8	> 20 KNOTS:	4.37E-5	8
AMOUNT GREATER:	X 4.17		AMOUNT GREATER:	X 2.41	
300 mb:	$[H^{\pm}]$	Events	300 mb:	$[H^{\pm}]$	Events
< 25 KNOTS:	1.07E-4	5	< 25 KNOTS:	1.51E-4	4
> 25 KNOTS:	2.82E-5	8	> 25 KNOTS:	3.47E-5	9
AMOUNT GREATER:	X 3.79		AMOUNT GREATER:	X 4.35	
AVERAGE AMOUNT GREATER (ALL PRESSURE LEVELS): X 3.37			AVERAGE AMOUNT GREATER (ALL PRESSURE LEVELS): X 2.59		

rain event (24 hours before the collection time). For every atmospheric level at both time intervals, the results show that the average acidity of rainfall was greater when winds were from the southwest, south, or southeast prior to the rainfall. The data show that on the average, when winds were from these directions 24 to 48 hours before rainfall, the hydrogen ion activity was about 3.2 times greater than when winds were from some other direction. For winds up to 24 hours before rainfall, a similar trend emerges, with acidity about 3.6 times greater with winds from the southwest, south, or southeast than that with winds from other directions.

In addition to wind direction, the acidity of rainfall was also correlated with wind speeds aloft, independent of the associated wind directions. Table 3 shows the effect of wind speed on acidity for the four pressure levels. For each pressure level, the wind speeds associated with the rain events were split into two nearly equal-size categories. For instance, the number of rain events with 850-mb winds less than 10 knots (six events) was approximately the same as the number with 850-mb winds equal to or greater than 10 knots (eight events). The category with the lighter wind speed for each pressure level corresponds to "light winds", whereas the other category corresponds to "strong winds". Light winds were closely correlated with highly acidic events. For the period considered here, the average acidity was about 3.4 times greater, when light winds prevailed 24 to 48 hours before a rain event, and about 2.6 times greater, when light winds prevailed up to 24 hours before the rain event. In only one category, 700-mb winds up to 24 hours before rainfall, did light winds tend to decrease acidity.

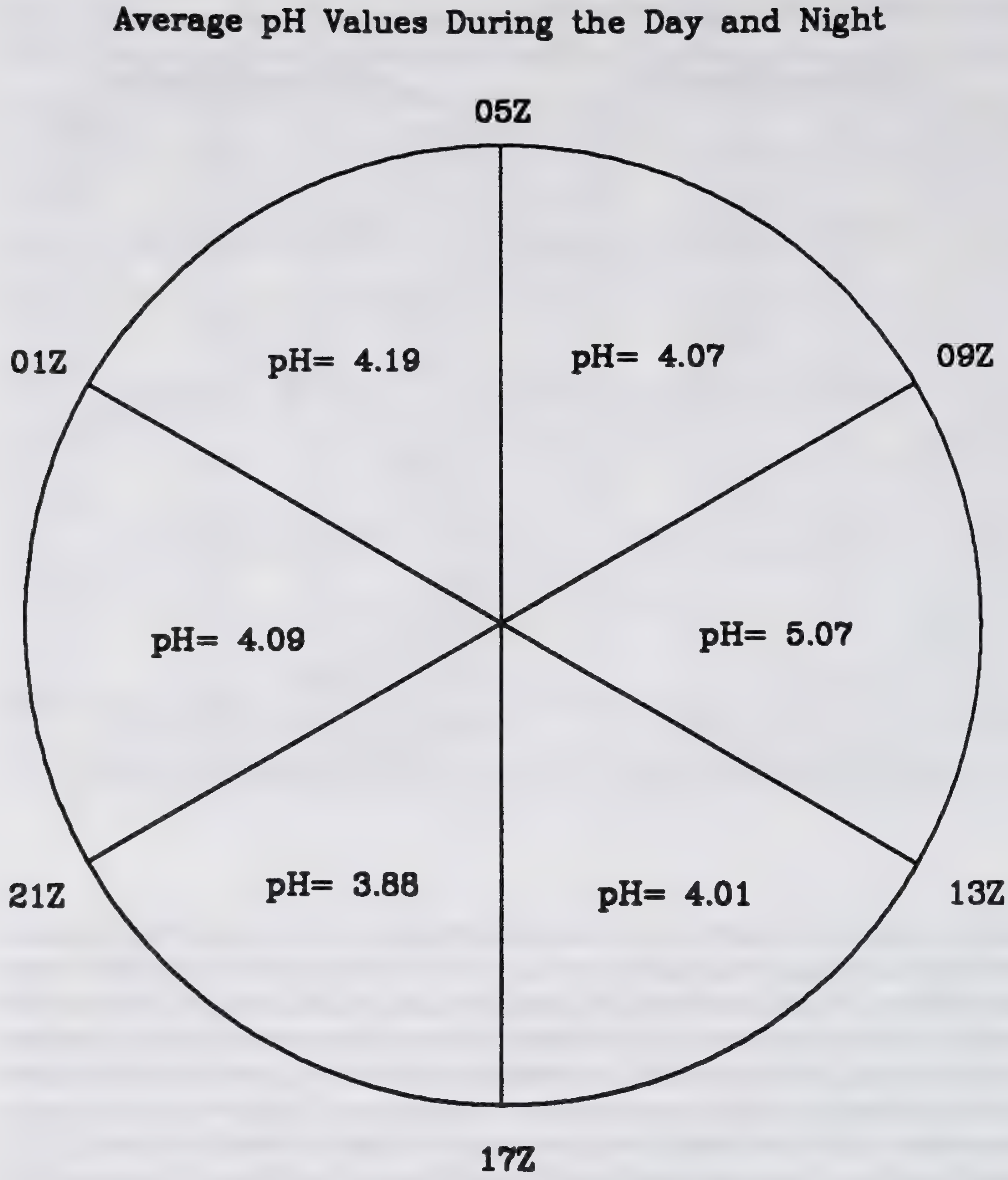


FIGURE 5. Effect of time of rainfall on acidity.

Rainfall amount. Another factor closely correlated with acidity was the amount of rainfall in an event. Figure 2 shows the average acidity, expressed in terms of [H+] for each type of rain event, categorized by amount of rainfall. Six events in the range 0.01 to 0.05 in. are listed as "light", and six in the range from 0.05 to 0.15 in. are listed as "moderate", while the six heaviest rainfalls, all in the range 0.15 to 2.00 in., are termed "heavy". The average pH was 3.9 for heavy rains, 4.3 for moderate rains, and 4.7 for light rains. A high degree of variation in acidity occurred, however, within this trend. The acid concentration varied from the least acidic event to the most acidic event for each rainfall type by a factor of 230 for light rains. In spite of this large variation, the average acidity of heavy rains was significantly greater than that of moderate rains (3 times as much).

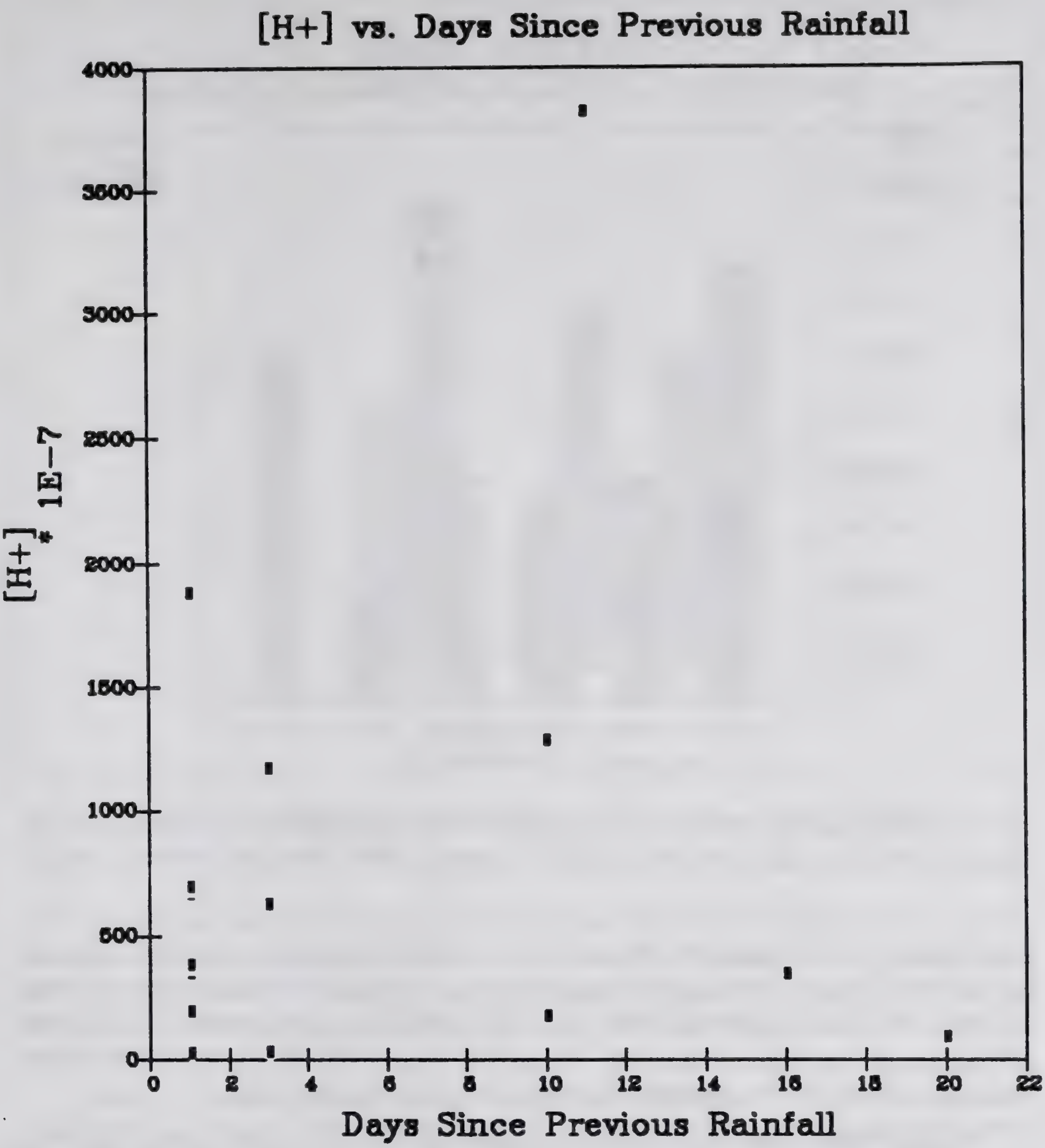


FIGURE 6. Effect of frequency of rainfall (day since previous rain) on acidity (all 18 events are shown, but some are clustered due to the scale used).

When the rainfall is very light, contamination of small samples through reaction with the walls of the collector is a concern. Experience (and a few simple laboratory checks) indicates that this effect should result in a decrease in the acidity of the sample, i.e., in an increase in its pH. It might also be anticipated that the longer the sample remained in the collector, the greater the decrease in acidity. However, no indication of this effect was found, as the two least acidic samples from the entire collection period (both from light rainfall) were analyzed within short times after the end of rainfall.

Rainfall rate and duration. Because the amount of rainfall in an event is determined by the rate and the length of rainfall, these two variables were analyzed to determine whether a similar correlation existed between their values and rainfall acidity. Average rates of rainfall were determined by dividing the

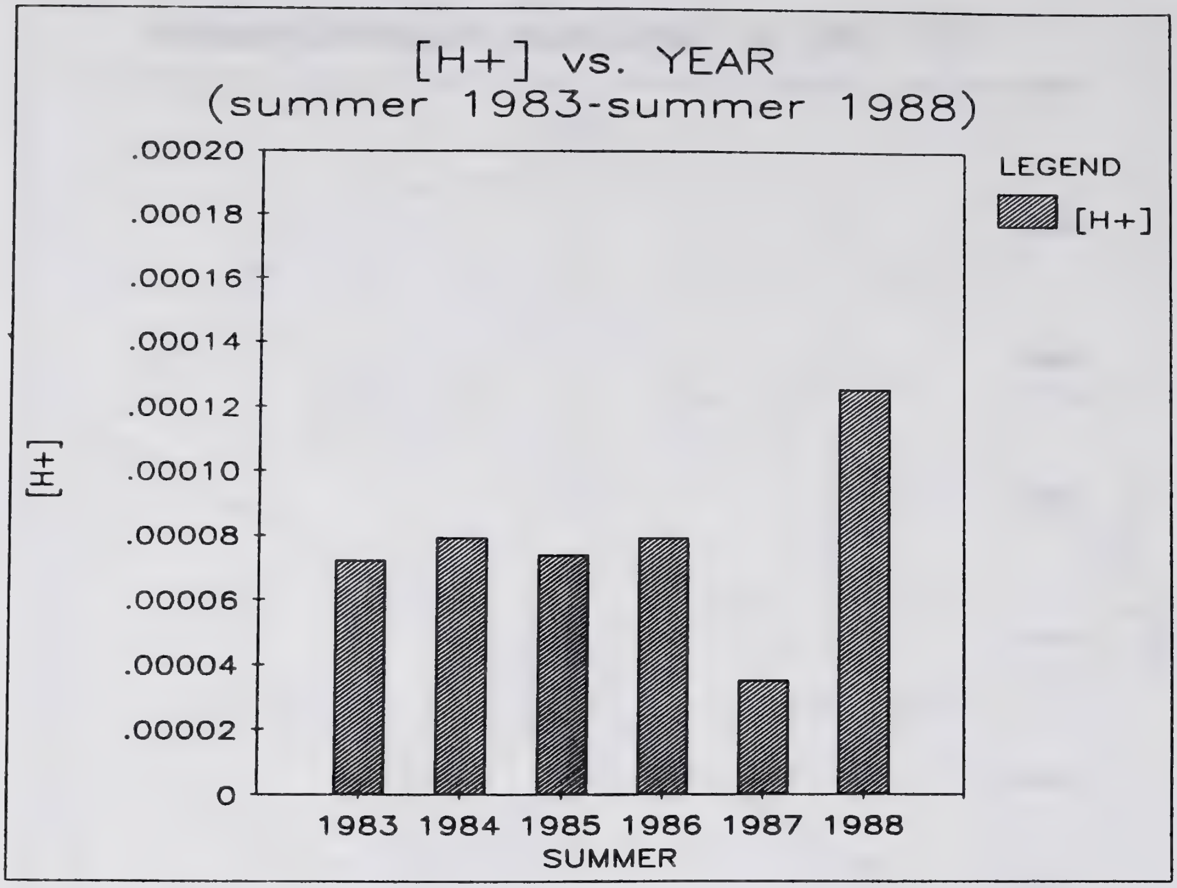


FIGURE 7. May to July averages of rainfall acidity at the collection site (six years; data for 1983 through 1987 from NADP records; 1988 data from current study).

total amount of rainwater collected by the total duration of the contributing rainfall. The resulting values are shown in the rightmost column of Table 1. For 14 of the 18 cases, there was only one rain event during the 24-hour sampling period; using a single average rate for the four days with two or more rain events in the 24 hours did not greatly effect the results presented here.

Figure 3 shows the relationship between the rate of rainfall and acidity. The rates were grouped into categories according to intensity. Five rainfall rates in the range 0.01 to 0.04 inches/hour are characterized as "slow", seven in the range from 0.04 to 0.06 inches/hour as "moderate", and six in the range from 0.06 to 0.50 inches/hour as "fast". Although fast rates (pH = 3.9) produced greater acidity than slow rates (pH = 4.2), the lowest acidity was associated not with slow rates but with moderate rates (pH = 4.8). Thus, no clear correlation is apparent between the rate of rainfall and rainfall acidity.

A much clearer correlation exists between the duration of rainfall and acidity (Figure 4). Once again the data were grouped into 3 approximately equal-size categories according to size. The six shortest rainfalls in the range (0.25 to 1.25 hours) are characterized as "short", the seven longest rainfalls in the range (4 to 4.5 hours) as "long", and the five remaining as "moderate". A pattern emerges that is similar to that between rainfall amount and rainfall acidity (Figure 2). Long rainfalls (pH = 3.9) tended to have more acidity than moderate rainfalls (pH = 4.3), which in turn tended to have greater hydrogen ion activity than short rainfalls (pH = 5.0). On the average, long rains were two times more acidic than

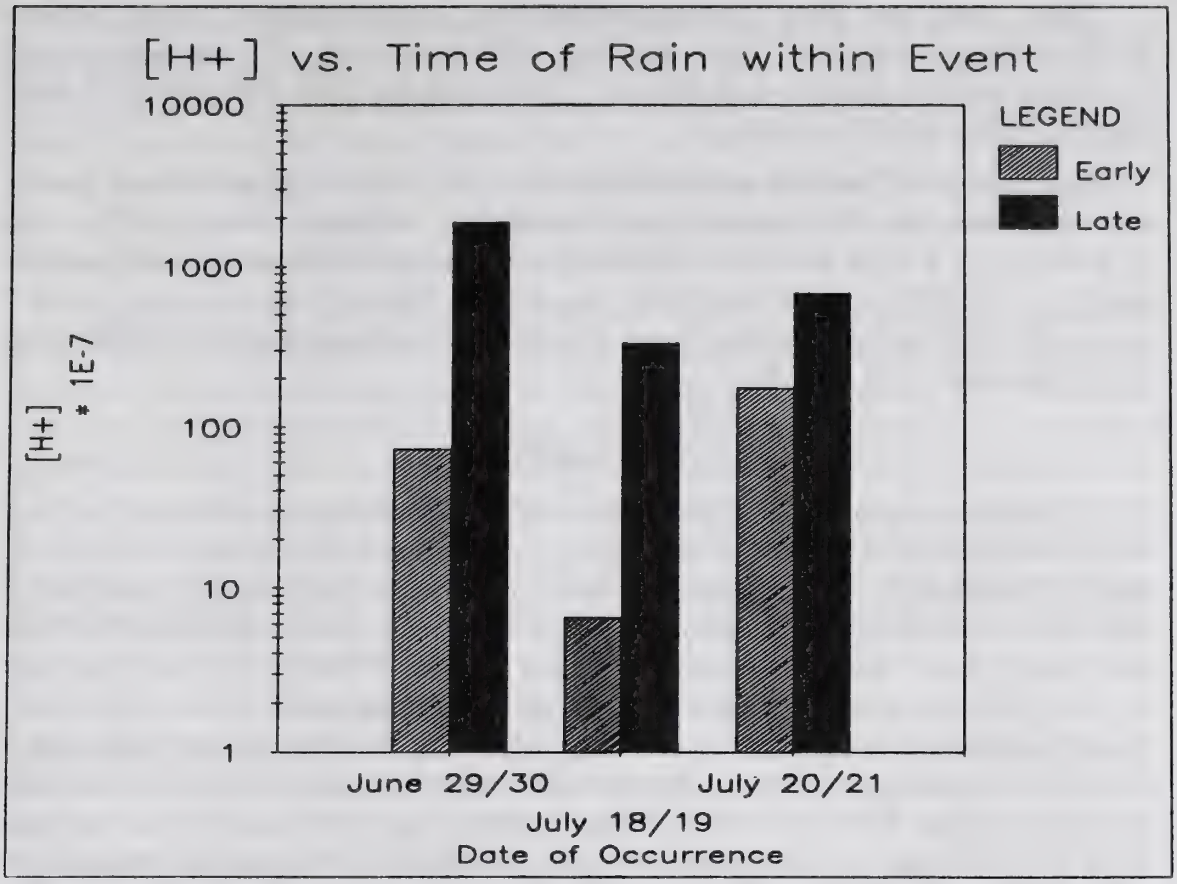


FIGURE 8. Effect of time of rainfall within a rain event on acidity (3 cases).

moderate rains and 14 times more acidic than short rains. Once again, a large amount of variation occurred within this trend. The hydrogen ion activity varied from the least acidic event to the most acidic event for each rainfall length by a factor of 22 for long rains, a factor of 16 for moderate rains, and a factor of 120 for short rains.

Time of rainfall. The time of rainfall also affected the acidity. Figure 5 represents a 24-hour clock partitioned into six four-hour intervals, starting at 5Z (midnight local time). The slices represent time intervals within which a rain event occurred. If an event spanned two or more time intervals, the pH of that event was averaged into each interval within which it occurred. The most acidic rainfalls occurred between 17Z - 21Z (noon - 4 p.m. local time), and the least acidic rainfalls occurred between 09Z - 13Z (4 a.m. - 8 a.m. local time). If one were to analyze daytime and nighttime rainfalls from the data, the approximate time intervals would be 01Z - 13Z (8 a.m. - 8 p.m.) and 13Z - 01Z (8 p.m. - 8 a.m.), respectively. The average daytime pH was 4.1, approximately 2 times as acidic as the average nighttime pH of 4.4.

Effect of preceding dry spells. Although intuitively one might expect more acidic rains following long dry spells due to the accumulation of pollutants in the atmosphere, this expectation is not supported by the data. Figure 6 shows the correlation of acidity with the number of days since the previous rain. This summer's drought provided a wide range of this independent variable (1 day to 20 days), but no correlation is apparent. The correlation coefficient (r) is only 0.14, indicating that acidity was probably independent of the time since the previous rainfall.

May, June, and July 1988 in perspective. A comparison of rainfall acidity for these 18 events in May, June, and July 1988 vis-a-vis that for the same period in recent years is presented in Figure 7. The data for 1983 through 1987 were obtained from NADP records.

The acidity of the 1988 summer's rainfall (pH = 3.9) is greater than that of any of the previous five summers and exceeds the five-year average (pH = 4.2) by a factor of 1.8 (80% greater than normal). A trend in summertime acid concentration since 1983 is not evident from the data. Although this summer's rainfall was much more acidic than the 5-year average, last summer's rainfall (1987) was much less acidic (pH = 4.5).

DISCUSSION

Pollution sources as far as 500 miles away can contribute significantly to wet deposition at a location, if the prevailing upper-air winds are favorable (GAO, 1984). Therefore, it is to be expected that when winds aloft are from regions of high sulfur-dioxide-emission prior to a rain event, the resulting rainfall will be more acidic than when these winds are from a region with few sources. The rain events in this study clearly show a tendency to be more acidic when winds aloft were from the regions of the heaviest burning of coal by power plants in the Ohio Valley (southeast, south, and southwest of the collection site) prior to a rain event. In addition, when light winds aloft prevail before a rain event, pollutants are less likely to be diluted by either eddy diffusion or forward stretching (the latter term refers to the dilution of pollutants as they are stretched in the direction of the wind, thereby reducing the concentration of pollutants in the air; Oke, 1978). For this reason, light winds aloft tended to produce highly acidic events.

As was mentioned in Data and Analysis Section, the amount of rainwater collected is a function of both the rate and the duration of rainfall. Since heavy rainfall events tended to be highly acidic, it is therefore reasonable to expect long rain events to be highly acidic as well. However, the question then arises as to why heavy rainfalls tended to be more acidic. A possible explanation stems from the fact that acid compounds are created within a cloud from oxidized sulfate and nitrate particles (SO_4 and NO_3) and their unoxidized gases (SO_2 and NO_3), with the compounds resulting from particles tending to be less acidic. Relatively alkaline solutions (derived from airborne soil particles) are also present and decrease the overall acidity of the cloud. If these particles of relatively higher pH are washed out at the beginning of a rain event, then the latter stages of the event will consist of raindrops which are more acidic. Perhaps, then, it is usual for a certain amount of less acidic rain to fall before the more acidic rain occurs. Thus, light rains and short rains might never reach the point when the more acidic rain begins.

This conjecture is supported by three instances during this study in which rainfall from the same weather system occurred both before and after a collection time. In all three instances, the rainfall at the latter stage of the event was more acidic, usually by large amounts (Figure 8 and Table 1).

Because rain dominated by convection tends to be more acidic than frontal-induced rain (General Accounting Office, 1984), the most acidic events should occur during the period of peak convective acivity. The higher acidity during the day and the especially high acidity from 17Z - 21Z (Figure 5) likely reflect this convective influence.

The lack of correlation between acidity and time since the previous rainfall (see Figure 6) is possibly due to the combined effects of dry deposition and atmospheric dust. If there is no rain for an extended period, ultimately dry deposition would be expected to balance emissions of pollutants into the atmosphere; the actual deposition pattern will be determined by the winds. This would suggest that after a sufficient period of time without rain, the first rain would be very acidic, if the atmospheric load of pollutants was large.

However, at the same time the pollutant load is building up, the amount of dust (which in general is alkaline and thus serves to neutralize acidic compounds) in the air increases as the surface dries out; lofting of dust depends on wind speeds and the extent of agricultural activity. Thus, when rain does finally occur after an extended dry period, the resulting acidity will depend on the relative proportion of pollutants and dust existing at that time. In a situation with significant dust in the air, a portion of the acidity of the rain would be neutralized, off-setting the increased load of pollutants in the air. This balance process was probably especially important in the drought of 1988 (37% of normal rainfall) with its numerous long periods of extreme dryness.

Why then was the rainfall in May through June 1988 still so much more acidic than that of the same periods in previous years (Figure 7)? A likely explanation would appear to be related to the fact that the extreme heat and dryness in 1988 was produced by an upper-air wind pattern that was dominated by an unusually persistent light, southerly flow that established itself in early May. Such a pattern would have strongly favored transport of an increased amount of pollutants from high SO_2-emitting regions to the study site and at the same time would have reduced dilution of pollutants by forward stretching or eddy diffusion while enroute. In addition, the persistent heat (29 days above 90° vis a vis normal of 14 days) and dryness of this period reflect the fact that those few fronts that did move through the area were weak and generally dry and did not lead to a significant change in the airmass over the droughty region. Most of the rain that did occur was produced by convective showers forming within the airmass and was, therefore, more acidic.

SUMMARY

The May, June, and July 1988 collection period was unusual in that only 37% of normal rainfall occurred, and the acid concentration greatly exceeded the 5-year summer average (1988 average pH = 3.90; 5-year average pH = 4.15). The 18 rain samples collected during the period indicate very acidic rainfall (50 times as acidic as naturally-occurring rain), although a great variation of acidity occurred (lowest pH = 3.42, highest pH = 6.53). When winds aloft were from known regions of high SO_2 emissions (southwest, south, and southeast of collection site) prior to a rain event, the resulting acid concentration of the rain was large compared with instances when winds were from other directions. In addition, wind speeds also affected the acidity, as light winds aloft produced higher acid concentrations in rainfall than strong winds. Heavy rains and long-lasting rains also produced relatively high acid concentrations, as did rainfall that occurred later in an event. The rate of rainfall, however, did not seem to affect acidity. Rain which occurred during the day produced higher acidity than nocturnal rain, with the most acidic rainfalls occurring between 17Z - 21Z. The time elapsed since the previous rainfall did not affect a rain event's acidity.

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ZOOLOGY

Chair: John S. Castrale
Forest Wildlife Office
R.R. 2, Box 477
Mitchell, Indiana 47446

Chair-Elect: Timothy J. Burkholder
Department of Biology
Taylor University
Taylor, Indiana 46989

ABSTRACTS

Use of Artificial Nest Sites by Spottail Darters. James H. Bandoli, Department of Biology, University of Southern Indiana, Evansville, IN 47712.——The spottail darter (*Etheostoma squamiceps*) is limited to a few small streams in Posey and Vanderburgh Counties. Previous studies suggest that the patchy distribution and generally low population densities seen in this species are due in part to a lack of suitable nesting sites (rocks or other large solid debris). To test this, between 10 and 20 half-cylinder sections of ceramic field tile were added as nest sites to the experimental halves of six stream sections. Each station was censused bimonthly from March 10 through May 23 for spottail darter nests. Of the 386 spottail darter nests found during the study, 122 (31.6%) were under tiles. The average nest contained 368.6 eggs, and tile nests and rock nests did not differ significantly in egg content. At least half the nests contained multiple clutches, and the smaller average nest size found in experimental areas suggests that the increases in nest availability may have allowed a decrease in the degree of polygyny. Densities of spottail darters did not correlate with the number of nests at each station, suggesting the possibility of local migration to and from breeding areas.

The Role of Visual Cues in the Reproductive Behavior of the Cichlid Fish *Astronotus ocellatus*. Simon C. Beeching, Department of Biology, Indiana University, Bloomington, IN 47405.——Visual cues, such as body size or color pattern, may be used by animals to assess potential mates or rivals, and thus serve a signal function in intraspecific interactions. The behavioral significance of body size and of two asepcts of color pattern in the cichlid fish *Astronotus ocellatus* was examined by presenting isolated adults with dummy conspecifics. As predicted, subjects spent more time interacting with, and directed more display behaviors toward, larger dummies. Frequencies of overt attack behaviors were not affected by dummy size. The dark-bar color pattern associated with juveniles and with defeated or frightened adults elicited fewer aggressive charges than the normal adult color pattern, suggesting it may serve an aggression inhibiting function. The species-typical ocellus on the caudal peduncle was shown to affect the spatial distribution of bites, and apparently functions as a target for bites in aggressive interactions.

Vagal Postganglionic Pathways to the Sinoatrial Node of the Dog Heart. K.M. Bluemel, M. Duff, M. O'Toole, W.C. Randall, and R.D. Wurster, Physiology and Biology Departments, Loyola University, Chicago and Taylor University, Upland, IN 46989.——Vagal ganglion cells which innervate the canine sinoatrial node (SAN) are located in the fat pad overlying and surrounding the right pulmonary vein complex (PVFP). Postganglionic fiber pathways from PVFP to SAN remain to be elucidated. A small bipolar stimulating electrode was applied to the ventral epicardial right atrium (RA) while recording from pickup electrodes on RA and right ventricle (RV). A third electrode pair was sutured to RA for pacing, and A-V conduction time was determined during simultaneous vagal stimulation and rapid atrial pacing. To prevent excitation of the atrium, stimulation was triggered during the RA refractory period. Response maps of stimulus-induced inhibition in rate were made by moving the stimulating electrode, both before and after hexamethonium into PVFP. Ganglionic blockade was evaluated by comparing rate and A-V intervals during vagal stimulation. The research confirms that ganglia in PVFP control SAN rate but *not* AVN conduction. Regulatory postganglionic fibers course directly from ganglia situated in PVFP across atrial myocardium and sulcus terminalis to SAN.

Population Response of Small Mammals to Emergence of Periodic Cicadas. Theodore J. Couillard, John C. Riddle, and David T. Krohne, Department of Biology, Wabash College, Crawfordsville, IN 47933.——In west-central Indiana, periodic cicadas emerged during the summer of 1987. We studied the population responses of two species of small mammals, the short-tailed shrew (*Blarina brevicauda*) and the white-footed mouse (*Peromyscus leucopus*), in old growth deciduous forest at Allee Memorial Woods field station in Parke County. Density estimates were made on a 3 hectare live-trapping grid using the direct enumeration method and compared with data obtained from the previous eight years when synchronous emergence of cicadas did not occur. Shrew densities in the forest were an order of magnitude higher in the year of cicada emergence than had been recorded in the previous years. There was no apparent effect on densities of white-footed mice. The effects of abundant insect prey on survivorship of the two species and reproduction will be discussed.

***Pseudosuccinea columella*, a Natural Host of *Schistosomatium douthitti* in Indiana**. David L. Daniell, Department of Biological Sciences, Butler Univ., Indianapolis, IN 46208.——*Schistosomatium douthitti* (Cort, 1914) Price, 1931 is one of two species of mammalian blood flukes found in North America. During June of 1988, one of 18 *Pseudosuccinea columella* collected along the north shore of Crooked Lake in Noble Co., Indiana was found to be infected with *S. douthitti*. Cercariae emerging from the infected snail were found to be identical in structure and behavior to those of *S. douthitti*. Adult male *S. douthitti* were recovered from the mesenteric veins of two laboratory mice (*Mus musculus*) 33 days and 59 days after exposure to these cercariae. This is the first record of *S. douthitti* in Indiana, and it is the first record of a natural infection of this blood fluke in the snail, *Pseudosuccinea columella*.

Selective Vagal Innervation of Sinoatrial vs. Atrioventricular Nodes in the Rat Heart. Kevin W. Firth, Steven K. Huprich, Walter C. Randall, and Tim Burkholder. Biology Department, Taylor University, Upland, IN 46989.——Vagal innervation of sinoatrial (SAN) and atrioventricular (AVN) regions of the rat heart has not been detailed; regulation of cardiac automaticity and conductivity requires further study. In 31 anethetized (Nembutal, 40 mg/kg) adult aniamls, electrical stimulation (20 Hz-2.0 msec-3.0-5.0 v) before and after selective surgical excision of ganglia were discretely located in four different sites (Pardini, JANS 20:91-101, 1987). Electrical potentials were recorded from right atrium, right ventricle, and ECG during vagal stimulation without, and with, atrial pacing. In contrast to vagal innervation of the canine heart, the anatomical course of right and left vagi into SAN and AVN are quite different. Each can be restrictively interrupted by surgical or chemical intervention, producing differential influences upon SAN (automaticity) versus AVN (conductivity) parameters of performance. Selective ablation of one (of four) epicardial fat pads deletes definable portions of cardiac regulation.

Effects of Lead Shot Ingestion on Mortality, Body Weight, and Concentrations of ALAD and Blood Lead in Mourning Doves. Johnson Ho, Mark Oster, Department of Life Science, Indiana State University, Terre Haute, IN 47809 and John S. Castrale, Indiana Division of Fish & Wildlife, R.R. 2, Box 477, Mitchell, IN 47446.——Mortality due to ingesting spent led shotgun pellets has been documented in mourning doves (*Zenaida macroura*). Our objectives were to measure the effects of lead shot ingestion on mortality rates, body weights, and concentrations of lead and the enzyme delta-aminolevulinic acid dehydratase (ALAD) in dove blood. Groups of 5 male and 5 female adult doves were dosed with 0, 1, 2, or 4 #8 lead pellets and monitored prior to dosing and 1, 5, 9, 14, 21, and 28 days after dosing. Three doves died (10% of dosed birds) during the experiment. Weight losses were related to the number of shot ingested, but survivors regained weight after passing shot by day 28. ALAD levels declinced from 95-99% within 24 hours after dosing and increased only slightly by day 28. Lead levels are currently being analyzed.

Status and Distribution of the Great Blue Heron in Indiana. George C. Iverson, Indiana Department of Natural Resources, Division of Fish and Wildlife, 3900 Soldiers Home Road, West Lafayette, IN 47906.—A statewide survey to monitor the status and distribution of great blue heron nesting colonies throughout Indiana was conducted by the Indiana Nongame and Endangered Wildlife Program in 1987. The purpose of this paper is to report the results of the 1987 Biennial Great Blue Heron Survey and compare these data with the previous 2 statewide surveys conducted in 1983 and 1985. A total of 58 active great blue heron nesting colonies were identified in 1987. The average colony size was 70.5 nests (SE = 10.2, range 1-395 nests/colony). Over 30% of all great blue heron nests (N = 4090) in Indiana occurrred in 5 colonies in 1987. More colonies (N = 23) occurred in the Great Lakes Plain physiographic region ($\bar{X} = 13.8$, df = 2, $P<0.01$) and fewer (N = 12) colonies were found in the southern Lexington Plain/Highland Rim region. The overall status of the great blue heron in Indiana improved from 1985 to 1987 with an increase in both the total number of active colonies and average colony size (N = 51 colonies, $\bar{X} = 56.1$ nests/colony in 1985). Conservation strategies are discussed.

Does Pretesting With Norepinephrine Affect the Response of Arterial Smooth Muscle to Vasopressin *In Vitro?* Thomas A. Lesh, Muncie Center for Medical Education, Ball State University, Muncie, IN 47306.——Prior to dose-response studies of hormone effects on isolated smooth muscle tissue, it is useful to test the viability of the preparation with a standard stimulus that will not alter the outcome of the study. The suitability of norepinephrine for such pretesting, as applied specifically to studies of arginine vasopressin (AVP), was evaluated in 8 pairs of arterial rings from Sprague-Dawley rats. Rings dissected from the abdominal aorta, with endothelium removed, were connected to isometric force transducers and maintained in baths of oxygenated Krebs bicarbonate solution. One ring of each pair was exposed to norepinephrine, 5 x 10^{-6} M; after this was washed out, cumulative dose-response curves for AVP were obtained on both rings. No significant differences could be shown between the responses of the 2 series of rings, and a correlation was found between the magnitudes of the standard norepinephrine and maximal AVP responses ($r = .915$; $P < 0.01$).

Serologic Relationships of the Rattlesnakes. SHERMAN A. MINTON, Indiana University School of Medicine, Indianapolis, IN 46223.——Antiserum against serum albumin of the rattlesnake *Crotalus viridis* was reacted against plasma samples from 16 other species of rattlesnakes, 11 pit vipers of 6 other genera, 6 species of *Vipera,* and 57 other species of snakes belonging to 9 families and 50 genera. Ouchterlony tests were used for screening samples. Species whose plasma gave a positive reaction at a concentration of 75 mcg/ml or less were further evaluated using radial immunodiffusion. Serologically rattlesnakes form a tight group with *Sistrurus miliarius* and *Crotalus horridus* most divergent. *Agkistrodon* (3 Asian and 3 American species) and the Asian *Deinagkistrodon* are rattlesnakes' closest serologic relatives followed by the neotropical *Bothrops asper, Hypnale* of Sri Lanka, and the 6 Eurasian species of *Vipera.* Most remote of the viperids are *Trimeresurus albolabris* and *Calloselasma rhodostoma* of southeast Asia. Plasmas of primitive snakes such as boids were nonreactive even at the highest concentrations used. Plasmas of the more advanced colubrids and elapids usually gave cross reactions at higher concentrations but few were reactive at 75 mcg/ml or less.

Dominance Interactions Among Familiar and Unfamiliar Dark-eyed Juncos. AMY MOORE and DORIS J. WATT, Department of Biology, St. Mary's College, Notre Dame, IN 46556.——We captured dark-eyed juncos (*Junco hyemalis*) from three different flocks in different areas around South Bend, Indiana, in March 1988. We combined experimental flocks composed of six birds from the same flock, "familiars," and six birds from another flock, "strangers," and introduced them into large indoor aviaries. Avoidance and attack behavior patterns of these groups are best explained using the sex-signalling hypothesis of plumage coloration.

Development of Osteoporosis in Ovariectomized Sprague-Dawley Rats. NANCY P. NEKVASIL and ANNA D'AMICO, Biology Department, Saint Mary's College, Notre Dame, IN 46556.——Ovariectomized Sprague-Dawley rats given various therapies were followed for a period of three months in order to examine the loss of bone that occurs with the absence of estrogen. The degree of bone loss varied based on the treatments following ovariectomization. Decreasing density of bone was demonstrated as follows: intact group (with ovaries), ovariectomized rats with estrogen replacement therapy (ERT) and calcium supplementation, calcium supplements alone, ovariectomized with no further intervention (3 months), and long-term post-ovariectomized (9 months) animal. Calcium theapy appears to aid in the delay of bone loss but calcium supplementation with estrogen is more effective. Severe osteoporosis was demonstrated in one animal who had been ovary-free for 9 months (equivalent to 27 human years). This animal had not had any estrogen or calcium supplements. Osteoporosis is visually detectable even by crude methods by 3 months after removal of the major estrogen source. With appropriate treatments soon after loss of ovarian function, it is possible to delay the onset and/or progression of osteoporosis.

The Presence of the Meningeal Worm, *Parelaphostrongylus tenuis* (Nematoda: Metastrongyloidea), in White-tailed Deer from Indiana, with Notes on the Gastropod Intermediate Hosts. THOMAS R. PLATT, Department of Biology, Saint Mary's College, Notre Dame, IN 46556.——Adults of the meningeal worm are reported from the brain of white-tailed deer in Indiana for the first time. Three of 9 hunter-killed animals taken at the Kingsbury State Fish and Wildlife Area during the 1987 hunting season were positive for adult *P. tenuis*. Collection of terrestrial gastropods, the intermediate hosts of meningeal worm, during the summer of 1988 was hampered by the extensive drought in the midwest. Examination of more than 300 individuals confirmed 1987 results that three species, *Discus cronkhitei*, *Cochlicopa* spp., and *Deroceras laeve*, are the principal candidates for local transmission of this parasite. The data were insufficient to identify local areas of transmission within Kingsbury.

Mate Choice in Zebra Finches. ELLEN M. ROTH and DORIS J. WATT, Department of Biology, St. Mary's College, Notre Dame, IN 46556.——Eleven female and 19 male zebra finches (*Poephila guttata*) were introduced into a large aviary containing eleven nests. Observations of mate choice, reproductive success, and pair fidelity were made over a four-month period. In 9 of 10 pairs, birds mated with others of their own color type.

Evidence for Tissue Degrowth in *Lymnaea* (Pulmonata, Basommatophora). DAVID A. SMITH and CHRISTOPHER C. HENDERSON, Wabash College, Department of Biology, Crawfordsville, IN 47933.——Adult *Lymnaea* were sampled from Sugar Creek, Crawfordsville, between October and December, 1987. Baseline analysis showed that tissue dry-weight (TDW) related to shell dry-weight (SDW) as, $TDW = 0.23\ SDW + 0.37$ ($r = 0.97$, $N = 160$, $P < 0.001$). This relationship was used as a predictor of TDW and differences between actual and predicted TDWs were used as estimates of tissue degrowth. Results showed significant levels of degrowth in *Lymnaea*. Tissue losses during ten weeks averaged -27% of predicted biomass (range of -3% to -41%). This level of tissue loss corresponds to that reported for *Helisoma* (50% loss in 132 days). Tissue losses here may be influenced by decreasing water temperature (to $< 4°C$) and by associated declines in algal biomass. Metabolic modifications, and their control, allowing individual survival during periods of degrowth are of significant physiological interest.

Rate and Temperature in Early Development of *Rana pipiens*. JASON S. VANLIESHOUT, Department of Biology, University of Notre Dame, Notre Dame, IN 46556 and GRAYSON S. DAVIS, Department of Biology, Valparaiso University, Valparaiso, IN 46383.——Fertilized *Rana pipiens* eggs can develop into tadpoles with nearly 100% viability over a wide range of temperatures (14-24° C); the higher the temperature, the faster is development. Within that range of viability and for *R. pipiens* from a given locale, the relationship between the rate of development to any given stage and temperature is linear. (If biochemical reactions were the rate-limiting step of development, this would not be the case.) Therefore, with a normal table of development for a given temperature and the regression of temperature and rate, an investigator can determine the time and temperature necessary to conveniently provide embroyos of any stage. We report: 1) normal tables of development for three novel, intermediate stages (between Shumway Stages 11 and 12) especially useful for experiments on gastrulation; and 2) that the regression between rate of development and temperature has not changed for Vermont *R. pipiens* from that reported by Bachman in 1940.

Physical and Biocheimcal Characterization of Insect Anti-freeze Proteins. DING WEN WU, JOHN G. DUMAN, and CHARLES A. KNIGHT[1], Department of Biological Sciences, University of Notre Dame, Notre Dame, IN 46556 and [1]National Center for Atmospheric Research, Boulder, CO 80307.——Overwintering larvae of the beetle *Dendroides canadensis* maintain high levels of thermal hysteresis producing proteins both in the hemolymph and in the mid-gut fluid. This presumably promotes freeze resistance by lowering the freezing point and promoting supercooling of the body fluids. The effects of various conditions including addition of Ab on the thermal hysteresis activity was determined for the *Denroides* proteins and for those from *Tenebrio molitor*. By slowly growing large hemispherical ice single crystals at very low antifreeze concentrations, it was shown that the proteins interact preferentially on the prism planes and thereby inhibit growth on these planes. The antifreeze proteins did not lower the short term nucleation temperature of buffer solutions which contained *Dendroides* hemolymph proteins with ice nucleating activity. However, the antifreeze proteins did stabilize the supercooled state over long periods.

Hormonal Control of Hemolymph Protein Involved in Cold Tolerance in Freeze Susceptible Insects. LEI XU and JOHN G. DUMAN, Department of Biological Sciences, University of Notre Dame, Notre Dame, IN 46556.——Initial studies (Horwath and Duman, 1983) showed that topical application of juvenile hormone induced thermal hysteresis protein (THP) production in larvae of the beetle *Dendroides canadensis*. These *in vivo* studies were extended to determine dose response curves for JH and the time course for induction of THPs. To monitor changes in THP levels, measurements of thermal hysteresis activity and immunoblots (Western blots and dot blots with polyclonal antibodies raised to purified THP) were used. As might be expected, dose response curves showed that the sensitivity of freshly collected larvae varied seasonally. Larvae were most sensitive in late summer while at certin times in early summer they were noninducible. JH application also stimulated THP production in *Tenebrio molitor* larvae. *In vivo* fat body culture demonstrated that the fat body is the site of THP production, both in *Dendroides* and *Tenebrio*. Addition of JH to the culture medium stimulated THP production in both species, but only when the fat body was taken from larvae pretreated with JH.

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RECENT POPULATION TRENDS AND HARVESTS OF NORTHERN BOBWHITE IN INDIANA

John S. Castrale and Steve E. Backs
Indiana Division of Fish and Wildlife
R.R. 2, Box 477
Mitchell, Indiana 47446
and
Robert E. Rolley
Indiana Division of Fish and Wildlife
300 West First Street
Bloomington, Indiana 47401

INTRODUCTION

The northern bobwhite (*Colinus virginianus*) is a familiar and welcome bird to rural Indiana residents, which is highly valued for its hunting qualities. Bobwhite populations are closely associated with early successional and ecotonal habitats resulting from agricultural operations. The bobwhite is distributed throughout the eastern United States and reaches the northern limit of its range in the States just north of Indiana.

Recent population levels and population trends of bobwhite quail in Indiana are recorded in this paper based on objective population surveys and estimates of harvest during legal hunting seasons. Comparisons are made to past surveys and harvests. Additionally, weather variables that might explain these fluctuations are examined.

METHODS

Population trends were established using two distinct surveys. The first was a breeding population survey conducted since 1976 by personnel from the Indiana Department of Natural Resources (DNR) during late June. The second data set was the U.S. Fish and Wildlife Service Breeding Bird Survey (BBS) that provides breeding indices beginning in 1966.

DNR survey routes were originally established and stratified based on major soil associations (Reeves, 1953). One hundred roadside routes were established in 1947, and each consisted of 8 to 10 stops spaced at one-mile intervals. The number of calling male bobwhite was tallied at each stop during a three-minute period. DNR surveys were conducted from 1947 to 1958, after which they were apparently discontinued. In 1976, DNR quail surveys were reinstituted, and from 29 to 43 of the original routes were surveyed annually through 1987. In 1988, the number of routes was increased to 71 in order to map more accurately the distribution and relative abundance of bobwhite in Indiana. The same routes were used each year, although some routes were replaced as a result of road closures or problems with excessive traffic. Beginning in 1986, the number of stops was increased to 15 by adding stops to the ends of routes. Each route was surveyed once during 20-30 June, beginning at sunrise on mornings with good weather.

The BBS is a roadside survey designed to monitor the distribution and population trends of birds in North America (Robbins, *et al.*, 1986). Forty-two routes

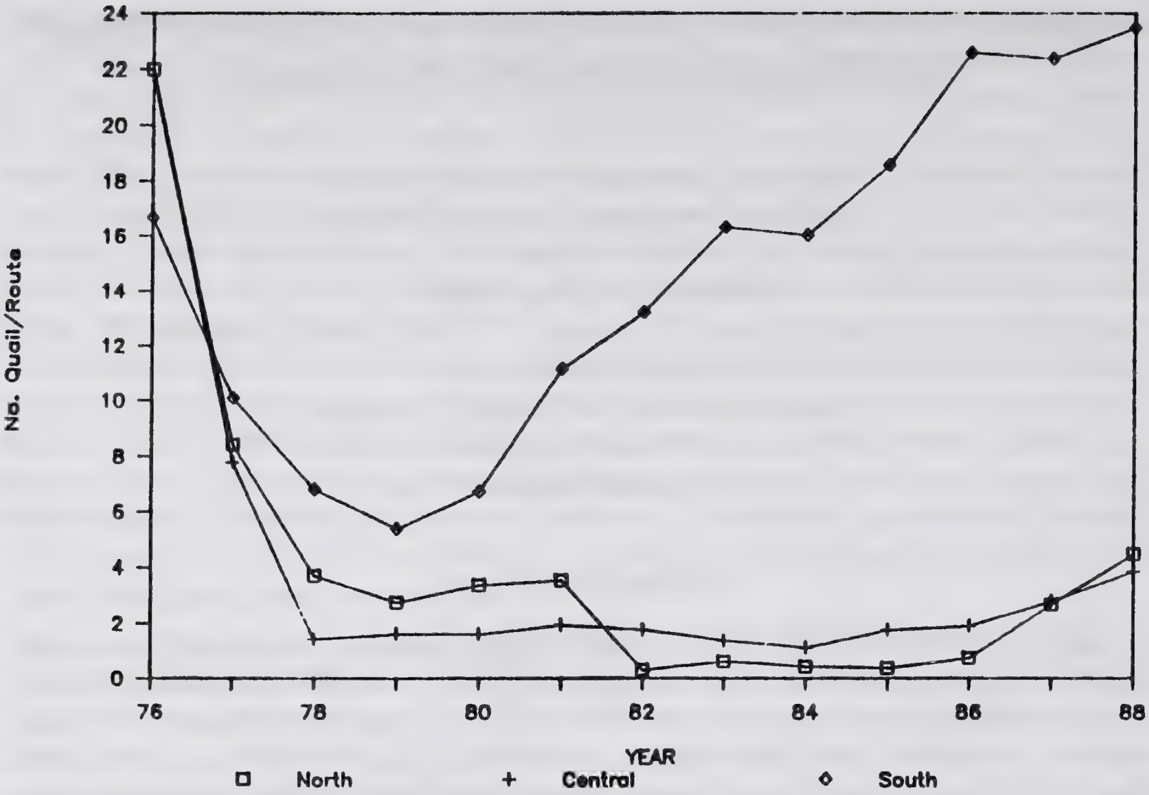


FIGURE 1. Regional population trends of bobwhite in Indiana based on DNR surveys from 1976 to 1988.

have been established in a stratified random manner in Indiana. Each route consists of 50 three-minute stops spaced at 0.5-mile intervals. Qualified volunteers survey each route once during June, beginning one hour before sunrise. All birds seen or heard within 0.25 miles of a stop are recorded. Each year from 1966 through 1987, 13 to 37 routes were surveyed. Only four of the 42 routes have not been surveyed at least once.

Results of the DNR and BBS surveys were handled in a similar manner. In the initial year of each survey, the number of quail detected was determined per stop for DNR surveys and per route for BBS. Subsequent annual population indices were calculated using changes in totals from comparable routes between each pair of successive years. Annual indices were calculated statewide and for northern, central, and southern regions of the State. Population surveys of northern bobwhite using counts of calling males is an accepted population monitoring technique but does not always accurately predict harvests (Rosene, 1957; Norton, *et al.*, 1961; Preno and Labisky, 1971; Ellis, *et al.*, 1972; Rosene and Rosene, 1972; Schwartz, 1974; Wells and Sexson, 1982).

Estimates of the number of quail hunters, harvest efforts, success rates, and total harvest were determined from post-season mail questionnaires. Questionnaires were sent to a random sample of hunters purchasing small game licenses each year since 1976 with the exception of 1982. From 1976 to 1987, usable questionnaires were received annually from an average of 5914 (range = 4742-8265) respondents, which represented 1.95% (range = 1.23-3.27%) of small game hunting license buyers. Harvest variables were adjusted for response and nonresponse biases, using correction factors developed for Indiana by Pfingsten (1980)

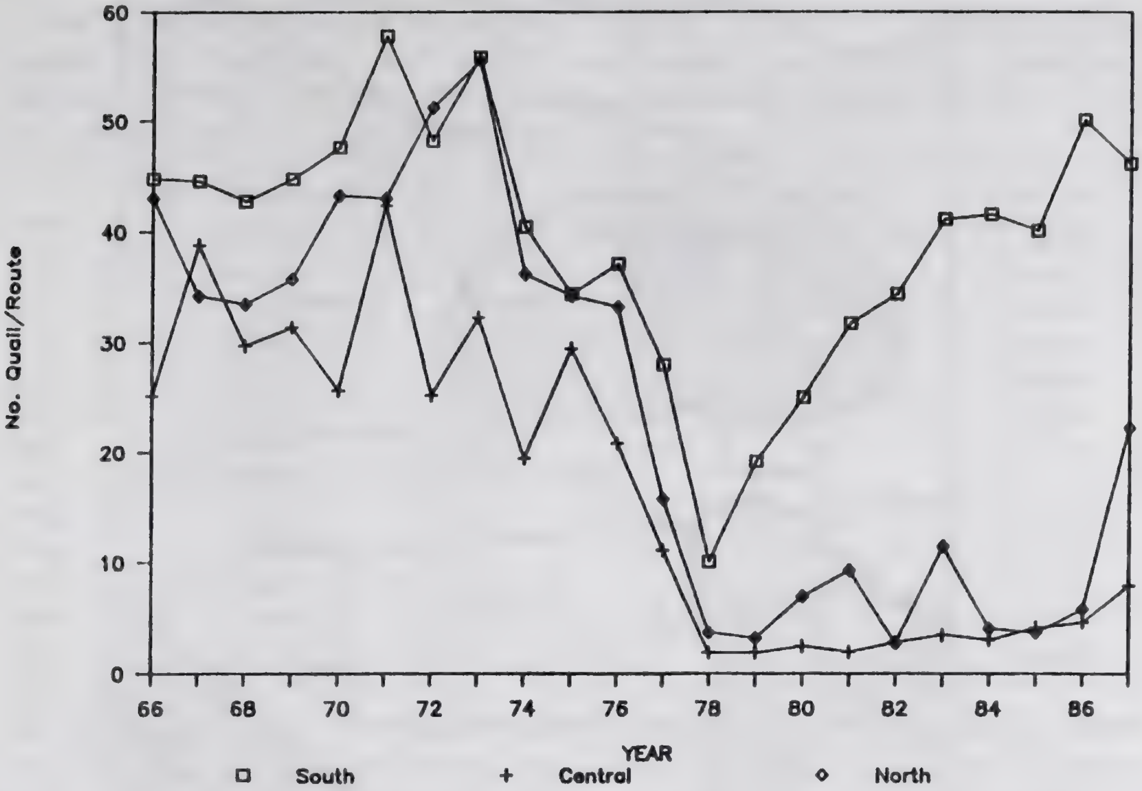


FIGURE 2. Regional population trends of bobwhite in Indiana based on BBS from 1966 to 1987.

and Rolley (1987). Therefore, our estimates of harvest and hunter numbers for these years differ from those previously published (Machan, 1986: p. 109).

Weather variables for the period December through March of the years 1965 to 1987 were compiled from annual reports of climatological data (National Oceanic and Atmospheric Administration, 1965-1987). For each winter (December-March), total snowfall and average temperature were extracted for three regions of Indiana (north, central, and south). Annual BBS indices of bobwhite populations for these regions were recalculated and examined statistically using these two weather variables. Simple correlations and multiple regressions were performed. Because annual indices are not independent events, the previous year's index was also used in the multiple regression models.

RESULTS

Population trends. Bobwhite populations as determined from DNR surveys were relatively high throughout Indiana in 1976 (Figure 1). A series of successive, harsh winters reduced populations by 84% by 1979 from 1976 levels. Recovery of bobwhite populations in southern Indiana was steady and attained levels comparable to pre-1977 levels by 1980. Populations in northern and central Indiana have not rebounded but are showing gradual increases.

BBS surveys showed similar population trends for the same period as the DNR surveys (Figure 2), but populations prior to 1976 were even higher. Bobwhite populations in southern Indiana had recovered to 1976 levels by 1982 or 1983. Regression analyses showed agreement between BBS and DNR surveys during

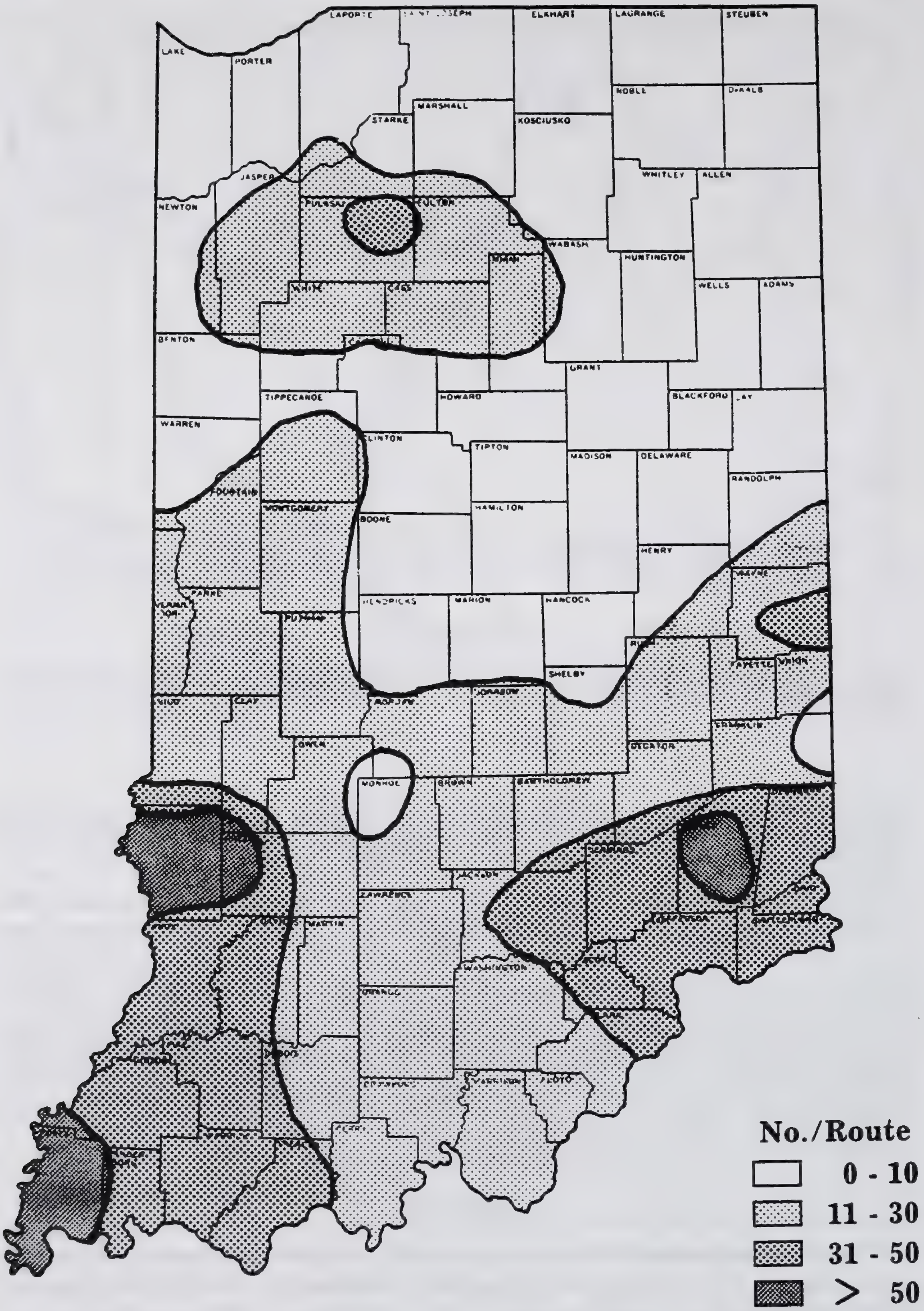


FIGURE 3. The relative distribtution of bobwhite in Indiana based on DNR surveys in 1988.

TABLE 1. Bobwhite harvest statistics for Indiana, 1976-1987. Excluded is information from landowners that legally hunt on their own property without purchasing a small game license. These landowners would add approximately 7% to the numbers harvested below (Castrale, *et al.*, 1985).

Year	No. hunters	Efforts/ hunter	Harvest/ hunter	Harvest/ effort	Bobwhite harvested
1976	100,679	6.03	3.51	0.58	353,826
1977	75,241	5.50	2.25	0.41	169,107
1978	60,667	4.94	1.18	0.24	71,315
1979	43,673	4.78	1.28	0.27	56,050
1980	33,002	4.87	1.43	0.29	47,079
1981	33,799	4.52	1.66	0.37	56,186
1982	—	—	—	—	—
1983	34,231	4.90	2.44	0.50	83,667
1984	27,966	6.13	2.15	0.35	60,197
1985	22,811	6.41	3.33	0.52	75,968
1986	21,880	6.94	3.73	0.54	81,672
1987	25,072	6.38	4.61	0.72	115,567

the period 1976-1987. The coefficient of determination (r^2) for statewide indices was 0.78 ($P < 0.01$) and was highest for central ($r^2 = 0.82, P < 0.001$) and southern ($r^2 = 0.87, P < 0.001$) regions. Northern routes had an r^2 of 0.68 ($P < 0.01$).

Approximately 50% fewer bobwhite are tallied per stop on BBS routes as on DNR routes. Bobwhite may be overlooked on BBS routes, because attention is also focused on other birds. Additionally, BBS include time periods (prior to sunrise and late morning), when bobwhite are less likely to call.

Population distribution. The current relative abundance of bobwhites in Indiana based on DNR surveys in 1988 showed highest numbers in southwestern and southeastern Indiana (Figure 3). Bobwhite were present on most routes except for some in northeastern Indiana. Southcentral, portions of central, and northwestern Indiana had intermediate levels.

DNR survey data for the same routes during the years 1952-1958 and 1987-1988 were mapped to compare the distribution and relative abundance of bobwhite (Figure 4). Differences in the statewide decline in numbers from the earlier period are apparent. The mean number of bobwhite/stop declined from 2.24 to 1.03. Sixty-one of 71 routes had fewer bobwhite during 1988. The proportion of the State that averaged < 1.0 bobwhite/stop increased from < 20% to almost 50%. Areas with > 3.0 bobwhite/stop declined from approximately 50% to < 5% of the State.

Harvest by sportsmen. From 1976-1987, the number of bobwhite harvested by licensed hunters ranged from over 350,000 in 1976 to less than 25,000 (Table 1). The number harvested was most highly correlated with spring indices ($r^2 = 0.94$, df = 9, $P < 0.001$) and the number of hunters afield ($r^2 = 0.69$, df = 9, $P < 0.01$). Other harvest statistics (efforts/hunter, harvest/hunter, and harvest/effort) were not significantly correlated with the number harvested. A regression model incorporating all harvest variables explained 96% of the variation in bobwhite harvested. Although statewide populations have rebounded to 44% of 1976 levels, harvests and hunter numbers are 33% and 25% of 1976 levels.

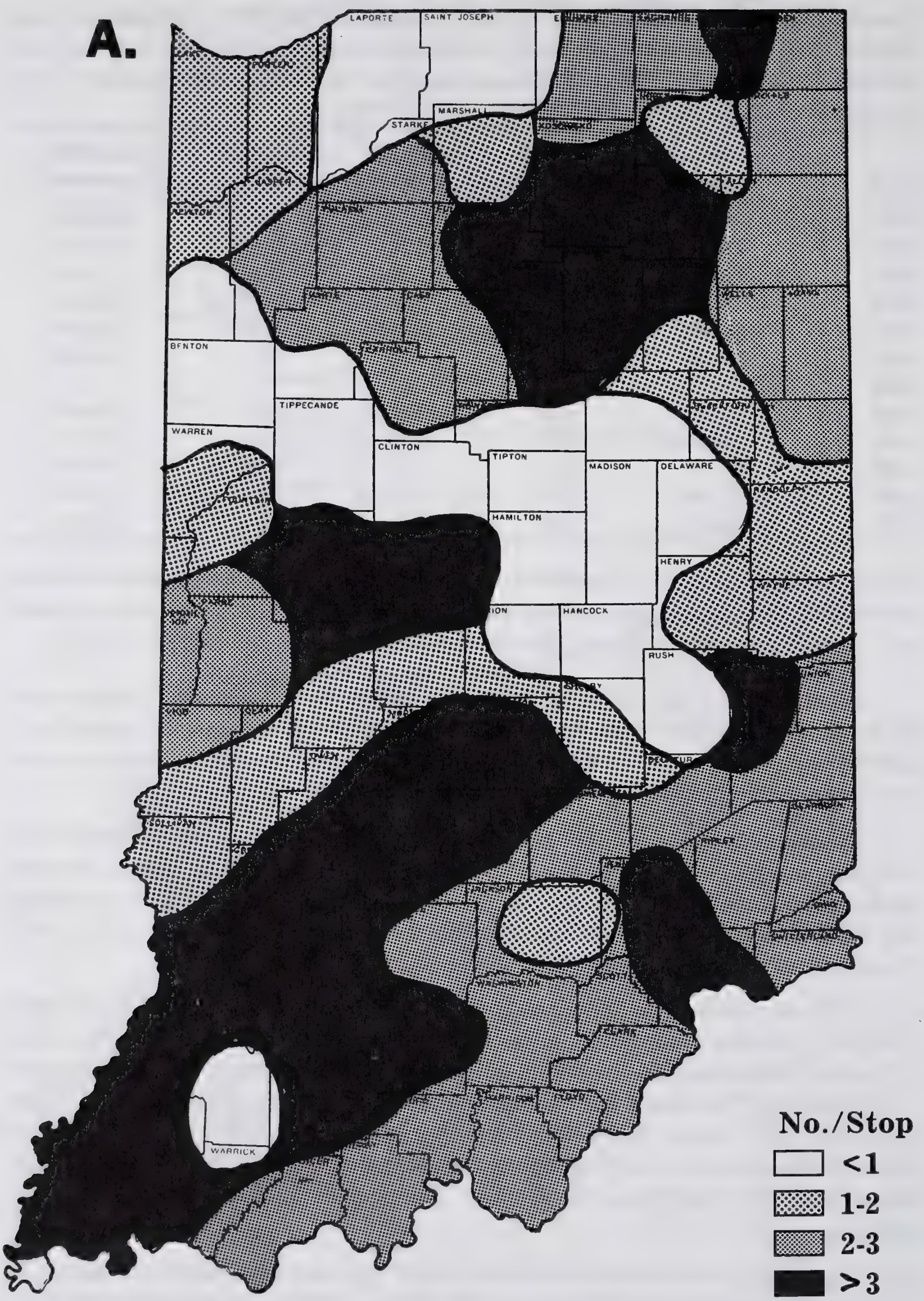
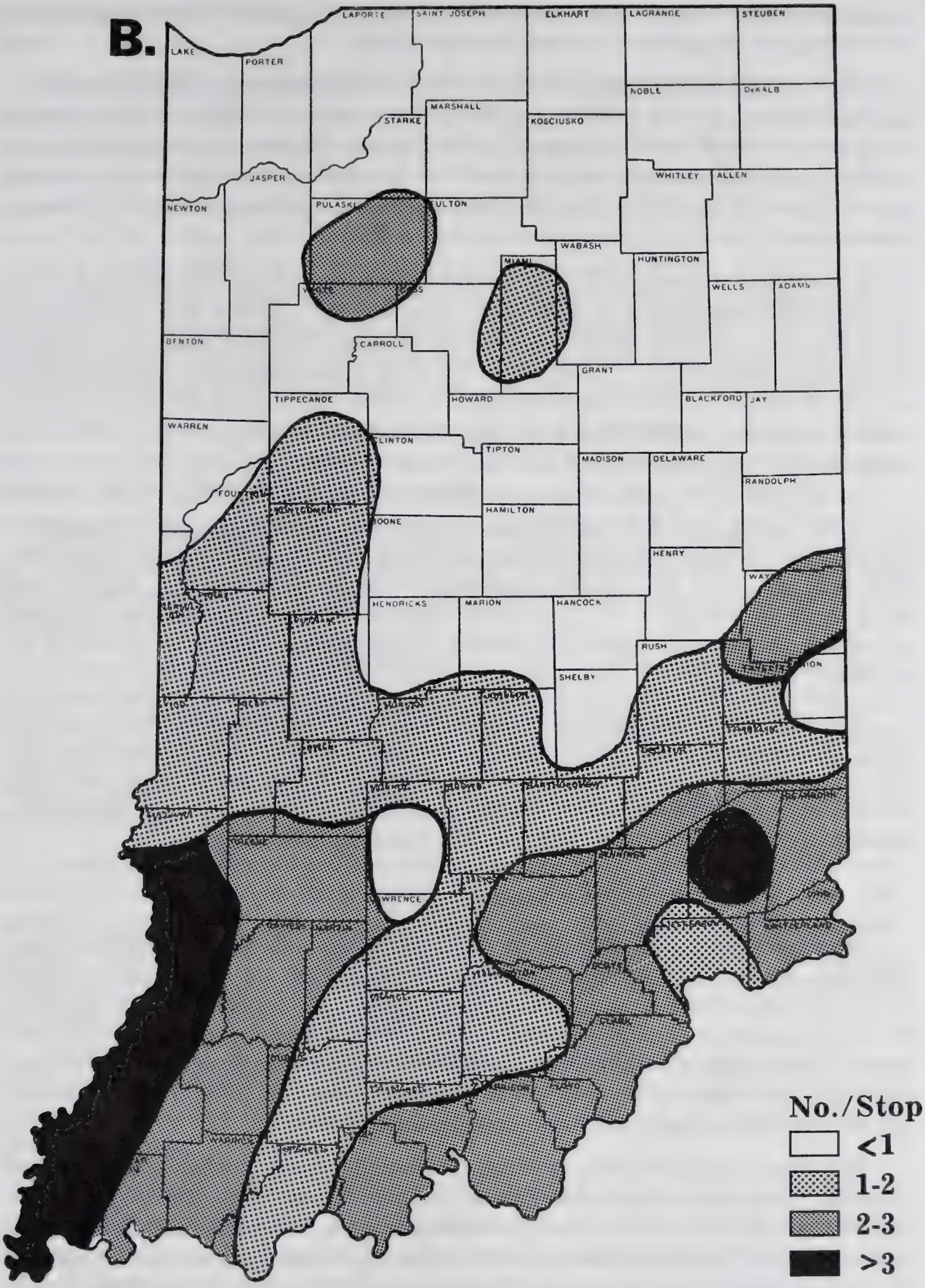


FIGURE 4. Relative distributions of bobwhite in Indiana for 1952-1958 (A) and 1987-1988 (B), using data from identical DNR survey routes.



Bobwhite hunting is better now than in 1976, if judged by the number harvested per hunting trip and the number harvested during the season by each hunter. The number of bobwhite harvested per hunter and per hunting effort fell sharply from 1976 levels to lows in 1978. These variables gradually increased thereafter, although increases have been more pronounced in the last several years. The number of efforts per hunter followed a similar trend, although differences were less pronounced. Thus, from 1976-1987, it appears that the more casual bobwhite hunters discontinued hunting during years when populations were lowest, leaving the more avid hunters afield.

For the period 1940-1954, 800,000 bobwhite were harvested annually by hunters, with as many as 1.5 million in 1940 (Reeves, 1955). Harvests again exceeded 1 million in the late 1950's (Machan, 1986). These estimates are certainly inflated relative to modern figures, because they fail to take into account various survey biases. However, it is likely that harvests were several times greater than during recent years.

Impacts of weather. Winter snowfall and mean daily temperature were significantly correlated with each other and with BBS indices in each region of the State. The inverse correlation between snowfall and BBS index was highest in southern Indiana (r = −0.61, df = 19, P = 0.003) and lower in northern (r = 0.47, df = 19, P = 0.028) and central (r = −0.43, df = 19, P = 0.045) Indiana. Annual winter snowfall for this period averaged 102 cm, 64 cm, and 42 cm for northern, central, and southern Indiana, respectively.

From 1966-1987, daily average temperatures during the winter were −1.94° C, −1.00° C, and 1.67° C for northern, central, and southern regions, respectively. Winter temperatures were positively correlated with the BBS index in southern (r = 0.55, df = 19, P = 0.008), central (r = 0.45, df = 19, P = 0.035), and northern (r = 0.41, df = 19, P = 0.059) Indiana. Winter temperature and total snowfall amounts were highly correlated (r ranged from −0.63 to −0.82) in all regions.

The best single predictor of the annual BBS index was the previous year's index. A model using the previous year's index and winter snowfall explained 70-90% ($P < 0.0001$) of the variation in BBS indices for each region for the 1966-1987 period. Adding winter temperature data resulted in less than a 2% addition to the predictive capabilities of the multiple regression models.

DISCUSSION

The distribution and abundance of bobwhite populations are constantly undergoing changes. Natural and man-induced influences are occurring that have short- and long-term consequences on the status of this species. Weather patterns, climatic changes, ecological succession, land use changes, farming practices, and other land management practices profoundly affect local and regional occurrence and numbers (Edwards, 1972; Exum, *et al.*, 1982; Klimstra, 1982). These processes are occurring simultaneously and interact with each other.

In Indiana, the distribution and relative abundance of bobwhite are influenced primarily by winter weather and habitat quality. The severity of winter weather that is more pronounced in northern Indiana causes periodic, sharp declines. In much of central Indiana, where row-crop farming is most intense, quality habitat is in short supply. In south-central Indiana, quality habitat is also suboptimal, because of large forested areas that are unsuitable for bobwhite. Currently, southeastern and southwestern Indiana appear to be most favorable for bobwhite due to mild winter weather and probably the most optimum mix of forested and open habitats.

Bobwhite benefited greatly during the period of European settlement as a result of the clearing of forests, the creation of openings, and the increase in food associated with cultivated land (Mumford and Keller, 1984). Reeves (1955) estimated that bobwhite populations in Indiana were greatest just after the Civil War.

Barnes (1947) mapped the distribution of bobwhite in Indiana based on the average number of birds shot per hunter for each county during 1940-1945. Relative distribution of bobwhite was similar to that in 1987-1988. Bobwhite harvests per hunter were decidedly greater in southern Indiana. Barnes explained this as a result of three factors manifested in northern Indiana: lack of cover due to intensive agriculture, colder winters, and greater hunting pressure. No counties north of Brown County were considered excellent, and only one county north of Vermillion County was considered good. Counties rated poor were in three distinct regions: the northern tier counties from Lake to Elkhart, the three northwestern counties (Benton, Warren, and Tippecanoe), and the 16 northeastern counties. Southern counties were rated medium to excellent and were relatively uniform.

Allen (1959) mapped the relative abundance of bobwhite in Indiana based on the seasonal harvest per hunter by county for the period 1940-1957. The general pattern was similar to that presented by Barnes (1947).

Mumford and Keller (1984) noted that bobwhite were susceptible to large-scale dieoffs during winters, when ice or crusted snow remained on the ground for extended periods of time. Butler (1898) noted such declines during the winters of 1878-1879 and 1892-1893.

Trends in abundance for a bobwhite population in southern Illinois from 1953-1980 were presented by Roseberry and Klimstra (1984). Fall populations appeared to exhibit a 10-yr cycle, and the overall trend was negative. Ohio populations were affected as dramatically by the severe winters of the late 1970's as were those in Indiana, and a large area of vacant range still exists (J. Henry, personal communication).

Roseberry and Klimstra (1984) stated that prolonged snow cover is the most detrimental weather condition for midwestern bobwhites. Heavy snow, wet weather in late winter and spring, heavy summer rains, and drought during the summer adversely affected populations in Illinois (Edwards, 1972). Kabot and Thompson (1963) noted that snow cover in conjunction with winter habitat limits the abundance and distribution of bobwhite in Wisconsin.

Stanford (1972) analyzed the influences of weather on Missouri populations. In years of severe snow and cold, bobwhite suffered mortality followed by reduced production. Recovery from weather-induced declines generally occurred two or three years later.

The number and distribution of bobwhite in Indiana will continue to depend primarily on land uses as they affect the quantity and quality of habitat. Winter weather conditions, however, will cause dramatic short-term changes. If winter conditions are average or favorable in the next decade, populations in central and northern Indiana should increase as bobwhite slowly repopulate areas from which they were locally extirpated in the late 1970's.

SUMMARY

Breeding populations of bobwhite were monitored from 1976 to 1988 using annual counts of calling males along 29 to 71 statewide routes and from 1966 to 1987 using Breeding Bird Survey data on 13 to 37 Indiana routes. In 1976, bob-

white were distributed statewide with similar population levels among northern, central, and southern regions. From 1977 to 1979, a series of harsh winters caused a 75-95% reduction in numbers throughout the State, and northern populations were again reduced following the winter of 1981. Populations rebounded in southern Indiana but are still depressed in northern and central portions of the State. Harvests by hunters experienced a similar trend, but kill figures have not increased to the extent that populations have. Population trends were influenced by winter snowfall and, to a lesser extent, by average winter temperatures.

ACKNOWLEDGMENTS

The time and efforts of personnel who conducted DNR and BBS survey routes are appreciated. G. Lange and C. Barron prepared the distribution maps. This study was funded by Federal Aid to Wildlife Restoration Project W-26-R and the Indiana Division of Fish and Wildlife.

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THE HERPETOFAUNA OF JEFFERSON COUNTY: ANALYSIS OF AN AMPHIBIAN AND REPTILE COMMUNITY IN SOUTHEASTERN INDIANA

Daryl R. Karns
Biology Department
Hanover College
Hanover, Indiana 47243

INTRODUCTION

The herpetofauna of southeastern Indiana (Jefferson, Jennings, Ripley, Dearborn, Ohio, and Switzerland Counties) has not been well studied. Hay (1892) in his classic survey of the Indiana herpetofauna notes a number of species collected in the area. Dury (1932) presents an account of species collected in Clifty Falls State Park near Madison, Indiana. Minton (1972) and Minton, *et al.* (1892) summarize current information on the status and distribution of amphibians and reptiles in Indiana.

Southeastern Indiana is a herpetologically rich area of the State. The region is especially notable for the abundance and variety of plethodontid salamanders and of snakes. The biogeographic affinities of the herpetofauna of southeastern Indiana are clearly with the south and eastern United States and are very different from the amphibian and reptile community found north of the Shelbyville moraine (Minton, 1972; Smith and Minton, 1957).

This report will summarize the results of a survey of the amphibian and reptile community of Jefferson County. The objectives of this study were to examine the distribution and abundance of different species in the common habitats of southeastern Indiana. The survey period ran from late spring through early fall (May through September) and provides a record of the composition and habitat utilization of the herpetofauna during the summer months. The effectiveness of different sampling methods was also documented.

STUDY AREA

Jefferson County, located in the southeastern corner of Indiana, is approximately 36.2 km wide and 41.8 km across with an area of about 948 square km. Information on physiography, vegetation, climate, geology, and soils can be found in Lindsey (1966), Homoya, *et al.* (1985), and Nickell (1985).

Jefferson County is a topographically diverse area that was not glaciated during the Wisconsin glacial advance. The county is located in the Bluegrass Natural Region (Homoya, *et al.*, 1985). This survey was concentrated in the Muscatatuck Flats and Canyons Section of that region. This section occupies the western half of the county and consists of a broad, gently sloping plain that breaks into the canyons that feed into the Ohio River valley. The flatlands are characterized by acidic, poorly drained soils, and the vegetation is dominated by the southern flatwoods community. The limestone canyons support a diverse, mixed mesophytic forest community. The Switzerland Hills Section occupies the eastern half of the county and consists of deeply dissected uplands. The ravine systems of this section are characterized by mixed mesophytic forests (Homoya, *et al.*, 1985).

MATERIALS AND METHODS

Drift fences were the primary sampling tool employed in this study. A drift fence is an artificial barrier with pitfall and funnel traps. Drift fences are effective at sampling small animals that move along the ground; small mammals and a variety of invertebrates are trapped as well as amphibians and reptiles. Data from ten drift fence sites are analyzed and form an important part of the data presented here. Drift fencing has inherent biases and shortcomings (Campbell and Christman, 1982; Gibbons and Semlitsch, 1981; Karns, 1986; Vogt and Hine, 1982). Hand collecting, road surveys, breeding call surveys, and turtle trapping were employed to supplement drift fence trapping.

Traditional hand collecting by overturning rocks, logs, and debris was employed throughout the survey in conjunction with checking drift fence sites. Separate collecting trips to sites of special interest were also made. Hand collecting was the primary method of sampling rocky creekbed environments.

Road surveys consisted of driving slowly along secondary roads at night looking for live animals. In addition, all roadkills encountered were identified and recorded. Commercial nylon-mesh turtle traps were used for turtle trapping. Anuran breeding sites were regularly visited and calling species identified.

A representative sample of the amphibians and reptiles collected were preserved as a voucher collection. This sample of about 350 animals is deposited in the Hanover College Biology Department collection.

Drift fence trapping. Each fence was a 15-m long section of 50-cm wide aluminum flashing (.019 gauge rolled aluminum). In habitats with no clear ecological gradients (e.g., large patch of woods), fences were set at right angles to each other about 50-m apart. This procedure corrects for directional bias in drift fence placement (Gibbons and Semlitsch, 1981). At other sites where there was a strong ecological gradient involving water (e.g., woods adjacent to a stream), both fences were set parallel to the water source. Previous experience showed that movement would be primarily to and from the water source (Karns, 1986).

A standard array of traps was employed at each fence. Each fence had two 20-L plastic bucket pitfalls (one at each end), four 7.6-L can pitfalls (two 3-lb. coffee cans taped together; two pitfalls on each side), and two funnel traps (1-m long, window screen cylinders with plastic funnels; one funnel trap on each side). Karns (1986) discusses drift fence construction.

Traps were checked at least once a week depending on the weather. For each amphibian and reptile trapped, the following information was recorded: species, length, weight, sex (if possible), side of fence trapped, and type of trap. Animals were toe-clipped (one digit) to allow recognition of previously trapped animals. Recaptured animals were excluded from the analysis.

Two 15-m drift fences in a given habitat were considered to be one fence site, and each day a site was open was counted as one trap day. Trap-rate was calculated as the number of animals trapped at a site divided by the number of trap days. Species diversity was calculated using the Shannon Diversity Index (H_s; Wilson and Brosset, 1977).

A total of 12 drift fences sites (two fences each) were placed in representative Jefferson County habitats (see below). These sites formed a rough north-south transect running through the central Muscatatuck Flats and Canyon Section of the County. Eight of these sites were open for over 100 days and are the primary source of information for this study. Two old field sites adjacent to small ponds were intermittently operational due to flooding and were open for a reduced number of days. Two forested sites were excluded from the final analysis due to vandalism. The trapping period was from May through September 1985 and April 15 through May 1986.

Drift fence site descriptions. The eight drift fence sites are described below. For each site, the location is indicated to the nearest $^1/_4$-$^1/_4$ section on 7.5 minute U.S.G.S. topographic maps. A brief qualitative description of the vegetation, topography, and soil-type at each site is given. The soil information is from Nickell (1985).

HV: HAPPY VALLEY (174 trap days): Madison West Quad. T3N, R10E, S7, NE$^1/_4$, SW$^1/_4$. Mature bottomland woods dominated by maple and beech in the upper canopy; maples dominate the understory; poison ivy and graminoids abundant. Fallen trees common due to extensive tornado damage in 1974. Happy Valley Creek runs through the site; fences located parallel to the creek; creek flow is intermittent depending on rain. Diverse soil types.

CF: CLIFTY PARK FIELD (123 trap days): Clifty Falls Quad. T4N, R10E, S33, NW$^1/_4$, NE$^1/_4$. Extensive field undergoing secondary succession; mosaic of shrubby and graminoid-dominated patches. Gently rolling field; fences located in patch with some shrubs, mostly graminoids. Cincinnati silt loam: deep, well drained soil; seasonal perched water table.

CW: CLIFTY PARK MATURE WOODS (135 trap days): Clifty Falls Quad. T4N, R10E, S29, NW$^1/_4$, NE$^1/_4$. Mature woods on bluff along Clifty Creek ravine; dominated by maple and basswood in the upper canopy; understory dominated by maples; poison ivy and mayapple common in ground layer. Fences located on level area overlooking Clifty Creek ravine. Cincinnati silt loam: deep, well drained soil; seasonal perched water table.

WW: WEBSTER WOODS (174 trap days): Kent Quad. T3N, R8E, S13, SW$^1/_4$, NW$^1/_4$. Forty-acre plot of second growth deciduous woods and planted pines; deciduous woods dominated by white oak, shagbark hickory, black oak, red oak; understory dominated by dogwood, beech, and maple saplings; common understory herbs: persimmon, poison ivy, greenbriar, and false Solomon's seal. Small creek runs through the site; fences located parallel to creek; creek flow is intermittent depending on rain. Bonnell silt loam: well-drained, strongly acid soil.

CP: CLIFTY PARK OLD FIELD POND (62 trap days): Clifty Falls Quad. T4N, R10E, S29, NE$^1/_4$, SE$^1/_4$. Large old field adjacent to mature maple-basswood forest. Shrubby field with a central wet area dominated by graminoids; two small ponds in wet area were active amphibian breeding sites. Fences set near pools adjacent to woods. Rossmoyne silt loam: level, deep, moderately well-drained upland soil. Site was prone to flooding.

HP: HORTON OLD FIELD POND (39 trap days): Clifty Falls Quad. T4N, R10E, S20, SW1/4, SE1/4. Shrubby old field adjacent to mature maple-basswood forest. Moderate sized (20-m diameter) shallow pond set in a depression. Pond dominated by cattails; active amphibian breeding site in the spring. Fence set near pond adjacent to woods. Cincinnati silt loam: sloping site with deep, well-drained soil. Site prone to flooding.

In following four descriptions, JPG refers to Jefferson Proving Ground, the U.S. Army Munitions Testing Base located in Jefferson, Ripley, and Jennings Counties.

JF: JPG FIELD (126 trap days): Clifty Falls Quad. T4N, R10E, S5, NW1/4, SE1/4. Extensive old field maintained by controlled burnings and mowing; diverse graminoid-dominated field being invaded by sweet gum and some sycamore; ragweed very common; area bordered by mixed hardwood forest. Level area with Avonburg silt loam: deep, poorly drained soil; seasonal perched water table.

JY: JPG YOUNG WOODS (126 trap days): Clifty Falls Quad. T4N, R10E, S6, NE1/4, NE1/4. Early successional, twenty year old patch of woods dominated by sweet gum and red maple in the upper canopy; oak and tulip in the understory; canopy trees of uniform age and height (6-10 m), forming open canopy; ragweed, flat-topped white aster, Joe-Pye weed common in understory; wetness of site indicated by large patches of moss (*Dicranium*) and numerous crayfish burrows. Extensive level area with Cobbsfork silt loam: deep, poorly drained soil subject to flooding; seasonal perched water table.

JM: JPG MATURE WOODS (126 trap days): Clifty Falls Quad. T5N, R10E, S31, SE1/4, SE1/4. Extensive patch of hardwoods located north of JY; subject to selective cutting in recent years but much older than JY. Upper canopy dominated by red maple; dogwood, pin oak, and sweet gum important; dogwood, ash, and tulip saplings abundant; graminoids, ferns, poison ivy, and partridgeberry common in understory. Level site; same soil as JY but better drainage.

JG: JPG GRAHAM CREEK (160 trap days): Holton Quad. T7N, R10E, S34, SE1/4, SE1/4. Riparian mature forest along Graham Creek. Diverse woods with no strong dominants: tulip, sugar maple, hickory, sycamore, black maple, and red and black oak all common; pawpaw thicket in immediate area of fence. Common understory plants: wingstem, Virginia knotweed, and stinging and false nettle. Fences located in woods immediately adjacent to the creek. Graham Creek is a permanently flowing stream. Holton loam: level, deep, somewhat poorly drained.

RESULTS

Species list. Table 1 is a list of the amphibian and reptile species of Jefferson County. The primary list of 49 species includes species collected during this study

TABLE 1. Species list of amphibians and reptiles for Jefferson County, Indiana. Species records from Minton (1972), Minton, *et al.* (1982), and this survey. Nomenclature follows Collins (1990).

	I	II	III	IV
CLASS AMPHIBIA (25 SPECIES)				
SALAMANDERS (13 species)				
Ambystoma barbouri (Kraus and Petranka, 1989)	K	I	D H	W
Ambystoma jeffersonianum (Spotted Salamander)	K ML	A	D	E
Ambystoma maculatum (Spotted Salamander)	K M	A	D	E
Ambystoma texanum (Smallmouth Salamander)	MR	U	NC	W
Notophthalmus viridescens (Red-spotted Newt)	K ML	A	D H	E
Desmognathus f. fuscus (N. Dusky Salamander)	K M	A	D H	E
Plethodon glutinosus (N. Slimy Salamander)	K ML	A	D H	S
Plethodon cinereus (Redback Salamander)	K MR	A	D H	E
Plethodon d. dorsalis (E. Zigzag Salamander)	K M	A	D H	S
Plethodon richmondi (Ravine Salamander)	K M	S	H	E
Eurycea cirrigera (S. Two-lined Salamander)	K M	A	D H	E
Eurycea l. longicauda (Longtail Salamander)	K M	S	D H	S
Eurycea lucifuga (Cave Salamander)	K M	S	D H	S
ANURANS (12 species)				
Bufo a. americanus (E. American Toad)	K ML	A	D H R	E
Bufo woodhousii fowleri (Fowler's Toad)	K M	A	D H R	W
Acris crepitans blanchardi (Blanchard's Cricket Frog)	K ML	S	D H	S

	I	II	III	IV
Pseudacris triseriata (Western Chorus Frog)	K M	A	D H	S
Pseudacris c. crucifer (N. Spring Peeper)	K ML	A	D H	E
Hyla chrysocelis (Cope's Gray Treefrog)	K ML	A	D	E
Rana clamitans melanota (Green Frog)	K M	A	D H R	E
Rana u. utricularia (Bullfrog)	K MR	A	H R	S
Rana sphenocephala (S. Leopard Frog)	K ML	A	D H R	S
Rana pipiens (N. Leopard Frog)	NC ML	U	NC	S
Rana palustris (Pickerel Frog)	K M	S	D H	E
Rana sylvatica (Wood Frog)	K M	A	D H	N
CLASS REPTILIA (24 SPECIES)				
TURTLES (7 species)				
Chelydra s. serpentina (Common Snapping Turtle)	K MR	A	R T	S
Sternotherus odoratus (Common Musk Turtle)	NC M	I	NC	S
Terrapene c. carolina (E. Box Turtle)	K M	A	D H R	E
Chrysemys picta marginata (Midland Painted Turtle)	K MR	A	R	S
Trachemys scripta elegans (Red-eared Slider)	K MR	I	T	S
Apalone m. mutica (Midland Smooth Softshell)	NC M	I	NC	S
Apalone s. spinefera (E. Spiny Softshell)	NC M	I	NC	S
LIZARDS (3 species)				
Sceloporus undulatus hyacinthinus (N. Fence Lizard)	K M	S	D H	S

	I	II	III	IV
Eumeces fasciatus (Five-lined Skink)	K MR	A	D H R	E
Eumeces laticeps (Broadhead Skink)	K M	U	D R	S
SNAKES (14 species)				
Nerodia sipedon pleuralis (Midland Water Snake)	K M	A	H	E
Regina septemvittata (Queen Snake)	K M	S	H	E
Clonophis kirtlandii (Kirtland's Snake)	K MR	S **	D H R	N
Storeria dekayi wrightorum (Midland Brown Snake)	K MR	U	H	S
Thamnophis s. sirtalis (E. Garter Snake)	K M	A	D H R	W
Coluber constrictor priapus (S. Black Racer)	K M	A	D H R	S
Elaphe o. obsoleta (Black Rat Snake)	K M	A	D H R	E
Lampropeltis triangulum (Milk Snake)	K MR	S	H R	S
Lampropeltis getula nigra (Black Kingsnake)	K MR	U	H	S
Opheodrys aestivus (Rough Green Snake)	K M	U	H	S
Diadophis punctatus edwardsii (N. Ringneck Snake)	K M	A	D H	E
Carphophis amoenus helenae (Midwest Worm Snake)	NC M	U	NC	S
Heterodon platirhinos (E. Hognose Snake)	K M	U	R	E
Agkistrodon contortrix mokason (N. Copperhead)	K M	S	H R	S

Symbols preceding species are as follows:

I. Source: K = Voucher specimen record from Karns.
NC = Not collected during this survey.
M = Voucher specimen record from Minton.
ML = Literature record from Minton.
MR = Range could include Jefferson County, but not actually collected from the county (from Minton).

II. Status: A = Widespread and abundant in suitable habitats.
S = Spotty distribution, abundant at specific sites.
U = Uncommon.
I = Insufficient collecting effort for this species.
C = New record for Jefferson County based on Minton.
*** = Indiana endangered species list.
** = Indiana threatened species list.
III. Method: D = Collected by drift fence.
H = Collected by hand.
R = Collected by road survey.
T = Collected by turtle trapping.
NC = Not collected.
IV. Biogeography: Geographic affinities of species according to Minton (1972).
N = Northern
S = Southern
E = Eastern
W = Western

(44 species) and other species verified by Minton (1972; Minton, *et al.*, 1982) on the basis of voucher specimens and literature records from the county. Species of possible occurrence in the county (11 species) are included in Table 2. The source of information, status, method of collection, and biogeographic affinity for each species is indicated on these tables. Nomenclature follows Collins (1991). Note that no attempt was made to search museum collections for additional records.

Many of the taxa listed in Table 1 are wide ranging species that are generalists in terms of their ecological requirements (Minton, 1972). The biogeographic affinities of the herpetofauna of Jefferson County are with the south and eastern United States. Minton's (1972) analysis of geographic derivations indicates that 24 species (49%) can be classified as southern, 19 species (39%) as eastern, four species (8%) as western, and two species (4%) as northern.

Comparison of drift fence sites. Ten drift fence sites were compared. The sites fall into four categories: 1) forest adjacent to streams; 2) forest without adjacent water; 3) old field with small ponds; and 4) old field without ponds. Note that the two old field pond sites were open for a reduced number of days compared to other sites.

Table 3 presents a comparison of the different sites. The three forested sites with an adjacent water source were the most productive sites in terms of species richness, abundance of animals, and species diversity. The richest site (JG) was the only forest site with a permanent water source (Graham Creek); WW and HV

TABLE 2. Species that may occur in Jefferson County, Indiana. Species noted by Minton (1972) as having ranges that could include Jefferson County that were not collected in the course of this survey. Numbers indicate my estimate of the probability of occurrence (1 = high; 2 = moderate; 3 = low). Source, status, and biogeography codes are the same as in Table 1.

Cryptobranchus a. alleganiensis (E. Hellbender)	3, ML, ***, E
Necturus m. maculosus (Mudpuppy)	3, MR, S
Gyrinophilus porphyriticus (Spring Salamander)	2, MR, S
Pseudotriton r. ruber (N. Red Salamander)	2, MR, ***, S
Ambystoma t. tigrinum (E. Tiger Salamander)	2, MR, W
Ambystoma opacum (Marbled Salamander)	2, MR, E
Scaphiopus h. holbrookii (E. Spadefoot)	3, MR, S
Graptemys geographica (Common Map Turtle)	1, MR, S
Nerodia erythrogaster neglecta (Copperbelly Water Snake)	1, MR, **, S
Thamnophis s. sauritus (E. Ribbon Snake)	2, MR, S
Crotalus horridus (Timber Rattlesnake)	2, MR, S

were adjacent to intermittently flowing creeks. The three forested sites without water were lower in species richness and abundance but similar in diversity index values to the forest creek sites.

Amphibians dominated the herpetofauna at the six forest sites; 93.3% of the forest animals trapped (n = 667) were amphibians, representing 20 species. Only 46 reptiles representing six species were trapped. The forest sites were generally similar in species composition. However, there was considerable variation in the abundance of particular species among sites.

Wood frogs were the most widespread and abundant woodland anuran (17.9% of the total 667 forest animals trapped; 6/6 forest sites) followed by American toads (11.5%; 4/6 forest sites) and green frogs (7.3%; 6/6 forest sites). Redback salamanders were the most widespread forest salamander (6/6 forest sites) and comprised 13.0% of the total trapped. Zigzag salamanders were found at fewer sites (3/6 forest sites) but were numerically more abundant (20.1% of the total trapped). Slimy salamanders, long-tail salamanders, cave salamanders, and red-

TABLE 3. Comparison of drift fence trapping at different sites in Jefferson County, Indiana, 1985-1986. See Materials and Methods for descriptions of the sites and calculations. Forest Creek refers to wooded sites adjacent to streams, Forest to wooded sites without adjacent water, Old Field Pond to early successional fields with small ponds, and Old Field Dry to fields without adjacent water. The mean (X̄) and standard deviation (S.D.) for each category are shown. Sites JF, JY, JM, and JG form a successional sequence from old field to climax forest. Note that the Old Field Pond sites were open for a reduced number of days.

Habitat	Site (days open)	Number of Species Trapped	Number of Animals Trapped	Trap-Rate	Diversity Index (H_S)
Forest Creek	JG (160)	17	203	1.27	2.26
	WW (174)	11	102	0.67	1.94
	HV (174)	13	219	1.26	1.37
X̄		13.7	174.7	1.1	1.86
(S.D.)		(3.06)	(63.44)	(0.34)	(0.45)
Forest	JM (126)	9	71	0.56	1.80
	JY (126)	10	28	0.22	2.13
	CW (135)	8	44	0.33	1.32
X̄		9.0	47.7	0.37	1.75
(S.D.)		(1.0)	(21.73)	(0.17)	(0.41)
Old Field Pond	CP (62)	6	16	0.23	1.87
	HP (39)	5	100	2.56	0.64
X̄		5.5	58	1.4	1.26
(S.D.)		(0.71)	(59.4)	(1.65)	(0.87)
Old Field Dry	JF (126)	4	5	0.04	1.33
	CF (123)	3	5	0.04	1.05
X̄		3.5	5.0	0.04	1.19
(S.D.)		(0.71)			(0.20)

spotted newts (eft form) were trapped in relatively low numbers and exhibited a spotty distribution.

Reptiles were infrequently trapped at forest sites (6.7% of the total forest animals trapped). Five-line skinks were the most commonly trapped lizard species (3/6 forest sites; 17 specimens). Garter snakes were the most frequently trapped snake (4/6 sites; 10 specimens). Broadhead skinks, southern black racers, ring-neck snakes, and Kirtland's snakes were occasionally trapped. Black rat snakes were collected but not trapped at forest sites. Box turtles were observed at all forest sites; one juvenile box turtle was trapped.

The old field sites were lower in species richness and diversity values than forested sites. The presence of water had a significant effect on the composition and abundance of the herpetofauna in old fields. The old field pond sites (HP, CP) exhibited a much higher trap-rate than dry old field (JF, CF) and were dominated by amphibians (only one southern black racer was trapped). The particularly high trap-rate at HP (2.6 animals per day) was due primarily to the emergence of recently metamorphosed green frogs from the pond. Cope's treefrogs, American toads, spring peepers, cricket frogs, pickerel frogs, zigzag salamanders, and spotted salamanders were also trapped.

These amphibians cannot be considered residents of the open field habitat. These are woodland species that are presumably using the field in a transient manner in movements associated with the pond, involving feeding, reproduction, and moisture requirements. The field pond data presented here are an underestimate of species richness and abundance at these sites due to the reduced number of trapping days and the fact that the survey did not include the major period of amphibian breeding in the spring. These data, although incomplete, demonstrate the influence of water resources on herpetofaunal utilization of old fields.

The dry old field sites (JF, CF) were depauperate compared to all other sites and were dominated by reptiles. The few reptiles (n = 10) trapped were garter snakes, southern black racers, and black rat snakes. However, these snakes and eastern box turtles were regularly observed. Only three amphibians were trapped in the dry old fields (two green frogs and an unidentified juvenile ambystomid).

A subset of the drift fence sites (JF, JY, JM, and JG) at Jefferson Proving Ground formed an old field successional sequence (Table 3). Changes in the herpetofauna were correlated with the successional stage of these sites. The reptile-dominated dry old field (JF) was the poorest of the four sites by all measures. The young (JY) and mature (JM) wooded sites were far more productive and had similar sets of species. The trap rate was higher at the mature (JM) wooded site indicating a larger amphibian and reptile population, but the younger (JY) site was more diverse. The oldest site with permanent water (JG) was the richest site by all measures employed. As noted above, amphibians dominated the forested sites. The Jefferson Proving Ground successional sequence did not include an old field pond site.

Species notes. The following observations are based on drift fence trapping, hand collecting, road surveys, and breeding call surveys.

Two species of the genus *Bufo* were collected. American toads were more common than Fowler's toad (4/6 forest sites) and were fairly abundant at three forest sites (HV, WW, and JM). Both species can be found in a range of habitats from woodland to open grassland, but Fowler's toad exhibits a habitat preference for loose, sandy soil (Minton, 1972). Site JG was the only site with this kind of substrate and the only site where Fowler's toad (21 trapped) was more common than the American toad (one trapped).

Frogs of the genus *Rana* are an important component of the Jefferson County herpetofauna. Bullfrogs, green frogs, pickerel frogs, and leopard frogs were often found in association with ponds, pools, and creeks. All these species may wander under appropriate weather conditions, and all ranid species except bullfrogs were trapped at sites distant from a water source. As noted above, the relatively terrestrial wood frog was the most widespread and abundant anuran. Southeastern Indiana is a zone of sympatry for the three local representatives of the *R. pipiens* complex (northern and southern leopard frogs, pickerel frog). The ecological interactions of these species are currently under investigation (Karns, unpublished data).

Breeding call surveys showed that species of the family Hylidae (spring peepers, chorus frogs, Cope's treefrog, and cricket frog) were common in the area. They were not well represented in the drift fence trapping due to their ability to escape from pitfall traps. The chorus frog was the most commonly trapped treefrog at forest sites (4/6 sites; 14 specimens).

Southeastern Indiana is rich in species of the family Plethodontidae. As noted above, redback and zigzag salamanders were the common woodland species. These species tended to have disjunct local distributions. Zigzags and redbacks comprised 96.2% (n = 126/131) and 2.3% (n = 3/131) respectively of the total salamanders trapped at HV. Rednecks comprised 59.3% of the salamanders trapped (n = 54/91) and 24.1% of those collected by hand (n = 45/187) at JG; no zigzags were collected. Hand collecting at several localities revealed this asymmetrical distribution. Zigzag and redback salamanders were collected in roughly equal numbers (zigzags: n = 7/120; redbacks: n = 10/120) at only one site in eastern Jefferson County.

Individuals of the all-red "scarlet" or "erythristic" color phase of the redback salamander were discovered at JG. This appears to be the only locality in Indiana where this color phase has been recorded. The nearest published locality for the color phase is in northeastern Ohio. Experimental studies indicate that erythristic redback salamanders may be a Batesian mimic of the toxic eft (Tilley, *et al.*, 1982). Preliminary surveys show that about 10% of the redbacks at the JG site are erythristic (Karns, unpublished data). This is the only site studied where efts were relatively common.

Other plethodontid species were locally abundant. Long-tail salamanders dominated the creekbed environment at JG (85.8%; n = 103/120 salamanders collected). Dusky salamanders dominated at West Fork Creek in the Switzerland Hills Section of eastern Jefferson County (81.7%; n = 98/120). Two-lined salamanders were dominant at Wolf Run Creek in the Switzerland Hills (100.0%; n = 27/27). These common creekbed species were rarely trapped in drift fences adjacent to streams. Cave salamanders exhibited the most unpredictable distribution of the salamanders collected. They were sampled in creekbeds, caves, and forests.

The secretive, burrowing salamanders of the genus *Ambystoma* are likely to be encountered on the surface only during movements associated with reproduction and overwintering. Spotted salamanders were trapped near breeding pools (CP) in the late spring. Jefferson's salamander was found only at one woodland site (JM) during this survey but has since been encountered in high numbers at drift-fenced ponds and appears to be common in the area. The tiger salamander and the marbled salamander may occur in Jefferson County, but they have not been detected.

A new species of ambystomid, *A. barbouri*, was described in 1989 (Kraus and Petranka, 1989). This species is a sibling species of *A. texanum*, the smallmouth salamander; it is a stream-breeding form found in southeastern Indiana, southwestern Ohio, and north-central Kentucky. Ambystomid larvae were observed in several streams in southern Jefferson county (Karns, unpublished observations), suggesting that *A. barbouri* is common.

The range map provided by Kraus and Petranka (1989) indicates that these sibling species are parapatric along the southwestern border of Jefferson County and that the range of *A. barbouri* includes the western half of Jefferson County (Switzerland Hills). The northwestern third of the county is shown outside the range of both species. I trapped one adult salamander near a pond in northwestern Jefferson County in November 1989 that was identified as *A. barbouri* on the basis of tooth morphology. This specimen indicates that the distributional limits of this species pair are in need of further study.

The red-spotted newt is the only member of the family Salamandridae found in Indiana. The aquatic form of the species (newts) were collected at several farm ponds. The terrestrial form (efts) were trapped at two forest sites (JG and HV). Efts were relatively common at JG (23.1% of the salamanders trapped; n = 21/91).

Lizards exhibited a spotty distribution. Five-lined skinks were trapped and observed at woodland sites with adjacent water (HV, JG, and WW). Broadhead skinks were trapped, but never observed, at only one woodland site (HV). Northern fence lizards were hand collected in drier, open sites.

Garter snakes, black rat snakes, and southern black racers were the most frequently encountered snakes in all habitats. Ringneck snakes were commonly encountered in moist woodlands. Kirtland's snake was restricted to woodland sites prone to flooding, where crayfish burrows were common (sites JW and JM). This species is known to use crayfish burrows as refuges, for estivation, and perhaps as overwintering sites (Sellers, 1986). The aquatic midland banded watersnake and queen snake were commonly encountered in creekbed sampling but never in drift fences. Ten other species were encountered infrequently and collected by hand or road surveys (Table 1).

Turtles were not adequately surveyed in this study; relatively little effort was put into turtle trapping. Snapping turtles, red-eared sliders, map turtles (Jennings County), and midland painted turtles were collected by turtle trapping and road surveys. The eastern box turtle was the most commonly encountered species. This terrestrial species was observed in all habitats.

Comparison of methods. Table 4 compares the effectiveness of the different sampling methods employed in generating the species list. Table 1 shows the methods of collection for each species. Because drift fences were the primary sampling tool, these are not comparisons of equal collecting effort. In spite of this inequality, drift fences and hand collecting produced a roughly comparable species list. Hand collecting was noticeably more effective than drift fences for snakes (twelve versus five species). The road survey was about half as effective as the other methods.

Table 5 presents a comparison of the effectiveness of the different traps employed with the drift fences. There was a significant difference in trap-rate among

TABLE 4. Comparison of effectiveness of different collecting methods for detecting species. The number of species collected by each method is shown. See Materials and Methods for a description of the techniques. Unique species refers to species collected only by that technique. The method of collection of each species is listed in Table 1. Drift fences were the primary sampling tool in this survey.

Taxon	Drift Fence	Hand Collecting	Road Survey
Salamanders	11	9	0
Anurans	10	11	6
Turtles	1	1	3
Lizards	3	2	2
Snakes	5	12	7
Total Species	30	35	18
Unique Species	3	6	2

trap-types ($\chi^2 = 489.46$, df = 2, $P < 0.001$). Overall, funnel traps were most effective followed relatively closely by 20-L buckets. The 7.6-L cans were a distant third.

The great majority of animals trapped were amphibians (95.5% of the total). Traps differed in their effectiveness with different amphibian taxa. Funnel traps were the most effective trap for salamanders. The primary reason for this is that some salamanders can crawl out of the buckets or cans. The drawback of funnel traps is that animals can quickly dessicate under dry conditions unless special precautions are taken. Twenty-liter buckets were about twice as effective at trapping anurans as either cans or funnel traps.

Relatively few reptiles were trapped in drift fences (4.5% of the total trapped). Medium-to-large sized snakes can easily slither out of buckets or cans; large snakes can go over fences. A few large snakes were trapped in funnel traps. Buckets or cans were effective with lizards, small-sized snake species, and juvenile snakes.

DISCUSSION

The herpetofauna of Jefferson County. It is common to discuss the animal community of a given area in terms of the plant community. However, with amphibians and reptiles, this approach probably gives the specific vegetation a greater role in determining the community composition of an area than is warranted. In their analysis of the herpetofauna of the Florida sandhills and scrub, Campbell and Christman (1982) noted that species responded to the physical characteristics of the habitat rather than to particular plant associations. My observations in southeastern Indiana agree with this conclusion.

In this study, three physical characteristics emerged as being of primary importance in determining site quality: 1) wetness of the site as determined by the presence and permanence of surface water and by soil type; 2) structural complexity of the habitat; and 3) microclimate as moderated by the first two factors. Thus, the fact that a site is a mature forest with a closed canopy and Cobbsfork silt loam (a poorly drained soil subject to flooding) is more important

TABLE 5. Comparison of effectiveness of different drift fence traps. Total number of animals of each taxon trapped by each type of trap is shown; numbers in parentheses are percentages. See Materials and Methods for a description of the traps. The data are a summary from 12 drift fence sites over a seven month period. Each site consisted of two fences with four cans, two buckets, and two funnels. Trap-rate is the total number of animals trapped divided by the total number of buckets deployed.

Taxon	**7.6-L Can (n=96)**	**20-L Bucket (n=48)**	**Funnel Trap (n=48)**	**Total**
Salamanders	53 (10.3)	129 (25.0)	333 (64.7)	515 (50.3)
Anurans	107 (23.2)	235 (50.9)	120 (26.0)	462 (45.2)
Turtles	0 —	1 (100.0)	0 —	1 (0.1)
Lizards	7 (31.8)	4 (18.2)	11 (50.0)	22 (2.2)
Snakes	0 —	2 (8.7)	21 (91.3)	23 (2.2)
Total	167 (16.3)	371 (36.3)	485 (47.4)	1023
Trap-Rate	1.7	7.7	10.1	

in predicting the composition of the herpetofauna than knowing that the forest is a maple-basswood climax community.

The classification of site wetness in Jefferson County is confounded by the high clay content of the soil and perched water tables (Nickell, 1985). Large areas of the County are level and poorly drained. These areas periodically become upland wetlands, whose continued existence is dependent on rainfall.

Another aspect of site quality is the distinction between primary and secondary habitat (Harris, 1984). Primary habitat is habitat in which a given species can meet all its life history needs. Secondary habitats fulfill only some of these requirements. For example, rocky creeks are primary habitat for dusky salamanders; they can feed, reproduce, and overwinter at these sites.

These different concepts of site quality are useful in discussing the survey data presented here. Structurally complex woodlands with forest moderated microclimate and adjacent water were the richest sites surveyed. The structurally simple, open field sites without adjacent water were the poorest sites. The nature of the water resource in a given habitat (stream, permanent pond, or temporary pools) is important in defining it as secondary or primary habitat, depending on the life history of a species.

Site quality obviously changes as ecological succession proceeds in abandoned farmland. For example, structural complexity increases and temperature fluctuations decrease (Smith, 1980). Secondary habitat may become primary habitat for some species as these changes occur. Old field succession is an extremely important process in Jefferson County, where acreage devoted to agriculture is decreasing, and farmland is being abandoned (Nickell, 1985). Changes in the herpetofauna associated with succession have received relatively little attention (Bennett, *et al.*, 1980; Harris, 1984).

The successional series examined in this study (Table 3) indicates that reptile-dominated, relatively low biomass, low diversity old field herpetofaunal communities are replaced by higher biomass, higher diversity amphibian-dominated communities as woodlands develop. This shift in community composition is not unexpected given the physiological differences between amphibians and reptiles. The situation is more complicated in old fields with water resources. Permanent and temporary ponds in fields attract amphibians and reptiles from adjacent woodlands for feeding and reproduction. The old field habitat becomes an important movement corridor in these cases.

The time period of the survey is important to consider in the interpretation of the data presented here. Southern Indiana has a relatively moderate climate. Large scale movements associated with amphibian breeding begin in January. Many species are active well into the fall, and some species are intermittently active all winter, depending on the weather (Minton, 1972; Karns, unpublished data). This survey compared habitats during the summer months only; movements associated with breeding and overwintering are largely excluded. The data presented here provide a portrait of the herpetofauna, when the majority of animals are presumably in summer feeding ranges. A survey conducted during the period of active breeding movements in the late winter and spring would provide a very different community portrait.

Methods of community analysis. Amphibians and reptiles are difficult to sample due to their secretive habits, sensitivity to environmental conditions, and seasonal patterns of activity (Vogt and Hine, 1982). This survey was not intended as a controlled comparison of sampling methods. However, in spite of the emphasis on drift fences, hand collecting provided a somewhat higher species count and comparable information on habitat utilization. Drift fences provide kinds of information not easily obtained by hand collecting (e.g., activity patterns and directionality of movement), but if the goal is a simple record of species occurrence and habitat utilization, the expense of drift fences may not be warranted.

The drift fence data show differences in trap success. Vogt and Hine (1982) suggest various arrangements of 20-L buckets, 7.6-L cans, and funnel traps for trapping different taxa in different habitats. The data presented here suggest that the 7.6-L cans could be eliminated. Some combination of 20-L buckets and funnel traps would be more effective. However, funnel lids on cans were not used in this study. Vogt and Hine (1982) found that funnel lids did improve the trapping effectiveness of the 7.6-L cans.

Future work. This survey has identified a number of questions that deserve further study: the distribution and status of the erythristic redback salamander, the ecological interactions of redback and zigzag salamanders, and the distribution of *A. barbouri* and *A. texanum*. For logistic reasons, this study concentrated on the Muscatatuck Flats and Canyons Section of Jefferson County. To the east lie the extensive uplands of the Switzerland Hills Section (Hay, 1892). This area is herpetologically understudied and warrants further investigation.

The data presented here clearly show the importance of woodlands for the amphibian and reptile community. The ecological reality of the herpetofauna of southeastern Indiana is a severely disturbed and fragmented habitat compared to the relatively continuous forest of pre-settlement times. The implications of habitat fragementation for the structure of amphibian and reptile communities is an important question for future study.

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BARN OWL FOOD HABITS IN INDIANA

Allen R. Parker
Indiana Department of Natural Resources
Division of Fish & Wildlife
Nongame and Endangered Wildlife Program
300 West First St.
Bloomington, Indiana 47403

ABSTRACT: Pellets from barn owls (*Tyto alba*) were collected in Indiana from 1983 to 1987. Skulls, mandibles, palate fragments, and non-principal prey parts were identified and tallied. Prey biomass was estimated using weights from the literature. Of the 12,905 prey items identified, 66% of them were voles (*Microtus* spp. and *Synaptomys cooperi*). Major prey buffer species were deer mice (*Peromyscus* sp.) and short-tailed shrews (*Blarina brevicauda*). Regional examination of food habits was conducted on 16 areas, and vole dependence ranged from 31% to 80%. The meadow vole (*M. pennsylvanicus*) was the most important prey species in all but the southwestern counties, where the prairie vole (*M. ochrogaster*) was most important. Seasonally, food habits varied only slightly. The mean weight per prey item was lower in Indiana than were those reported for other States.

INTRODUCTION

The common barn owl (*Tyto alba pratincola*) is on endangered species lists in 7 midwestern states (Rosenburg, 1986), and its decline has been attributed to changes in agricultural practices (Colvin, 1985). Past research in the Ohio Valley and the eastern United States has revealed that the meadow vole (*Microtus pennsylvanicus*) is the primary prey of the barn owl (Colvin and McLean, 1986; Pearson and Pearson, 1947; Rosenburg, 1986). Analysis of small collections of barn owl pellets from Indiana supported this finding (Castrale, *et al.*, 1983). Until now, however, a statewide analysis of barn owl food habits has not been reported. Variations in barn owl foods from 24 counties in Indiana and notes on incidental small mammal occurrences are reported in this paper.

METHODS

In 1983, the Nongame and Endangered Wildlife Program of the Indiana Department of Natural Resources initiated a search for barn owls by eliciting public reports. Report areas were searched and barn owl presence was verified by pellets. Nest boxes were placed in barns in most of these areas, and pellets were gathered during searches and nest box examinations. From October, 1983, to March, 1987, 2539 pellets and 4 pellet masses were collected from Indiana nest and roost sites. Pellets were air dried, labelled, and stored in plastic bags in a cool location. Pellets were sorted by date and locality. Groups of fewer than ten pellets were dissected by hand. Large groups of pellets were crumbed and placed in a heated solution of 2% NaOH at a rate of 100 ml pellets to 1000 ml solution (Schueler, 1972), until bones were easily separtated from dissolved hair.

All skulls, palate fragments, and mandibles were tallied as were all parts not recognized as vole, shrew, or mouse. Collections from Indiana State University and published keys (Glass, 1973; Hall, 1981; Mumford and Whitaker, 1982) were used to identify mammalian and avian prey. As a result of tooth loss during chemical digestion, some items had to be classified as unknown voles (*Microtus* spp.), unknown mice (*Peromyscus, Mus, Zapus* spp.), and unknown shrews (*Sorex* spp.). Limitations of digestion also led to combining deer mice (*Peromyscus maniculatus*) with white-footed mice (*Peromyscus leucopus*) and pine voles (*M. pinetorum*) with prairie voles (*M. ochrogaster*). Counted bird bones included skulls, beaks, femora, sterna, and synsacra. The highest count of prey parts for each prey group was used as the total number of that prey. The total number of unknown species parts was reduced by the number of known species parts which they could have duplicated. Thus, the unknown vole, mouse, and shrew counts are minimum estimates.

To estimate biomass of mammalian prey, mean body weights were taken from Mumford and Whitaker (1982) as follows: meadow vole (*Microtus pennsylvanicus* = 38.5 g), prairie vole (*M. ochrogaster* = 35.4 g), pine vole (*M. pinetorum* = 26 g), southern bog lemming (*Synaptomys cooperi* = 27.3 g), deer mouse (*Peromyscus maniculatus* = 16.2 g), white-footed mouse (*P. leucopus* = 21.1 g), house mouse (*Mus musculus* = 17.4 g), meadow jumping mouse (*Zapus hudsonius* = 18.2 g), short-tailed shew (*Blarina brevicauda* = 16.9 g), least shrew (*Cryptotis parva* = 4.5 g), southeastern shrew (*Sorex longirostris* = 3.1 g), masked shrew (*Sorex cinereus* = 3.7 g), least weasel (*Mustela nivalis* = 38.3 g), eastern mole (*Scalopus aquaticus* = 107.1 g), and big brown bat (*Eptesicus fuscus* = 17 g). Averages of weights were used for the combined groups. Biomass figures for the Norway rat (*Rattus norvegicus*) were calculated from mandible measurements (Morris, 1979), but partial rat jaws were assigned the mean rat weight of 68 g. Young cottontail rabbits (*Sylvilagus floridanus*) were assigned a 90 g biomass (Colvin and McLean, 1986). Occurrences of large mammals were represented by the largest estimate of biomass of any one pellet (250 g). Bird weights were assigned according to the size of the bird parts found and ranged from 30 g to 100 g.

RESULTS

Statewide. A total of 12,905 prey items was identified from the pellets analyzed, and the total biomass of these individuals was 376 kg. Voles (*Microtus* spp. and *Synaptomys cooperi*) were 67.8% of all prey items taken and made up 80.1% of the total biomass. Meadow vole was the most important prey species, comprising 29.7% of the total items (Figure 1) and 39.2% of the total biomass (Figure 2). The prairie vole represented 27.1% of frequency and 28.6% biomass, and unknown voles were an additional 9.6% frequency and 11% biomass. Short-tailed shrew and deer mice made up 9.8% and 8.1% of the frequency and 5.7% and 5.2% of the biomass, respectively. Of 228 *Peromyscus* spp. skulls which could be identified to species, 64% were *P. maniculatus*, and 36% were *P. leucopus*. Due to their small size the house mouse and least shrew comprised less biomass (2.6% and 0.6%) than frequency (4.3% and 4.1%, respectively). Other mammals were less than 2% of the owl diet by frequency or biomass. Of interest are occurrences of big brown bat, least weasel, and young oppossum (*Didelphis virginiana*). Red-winged blackbird

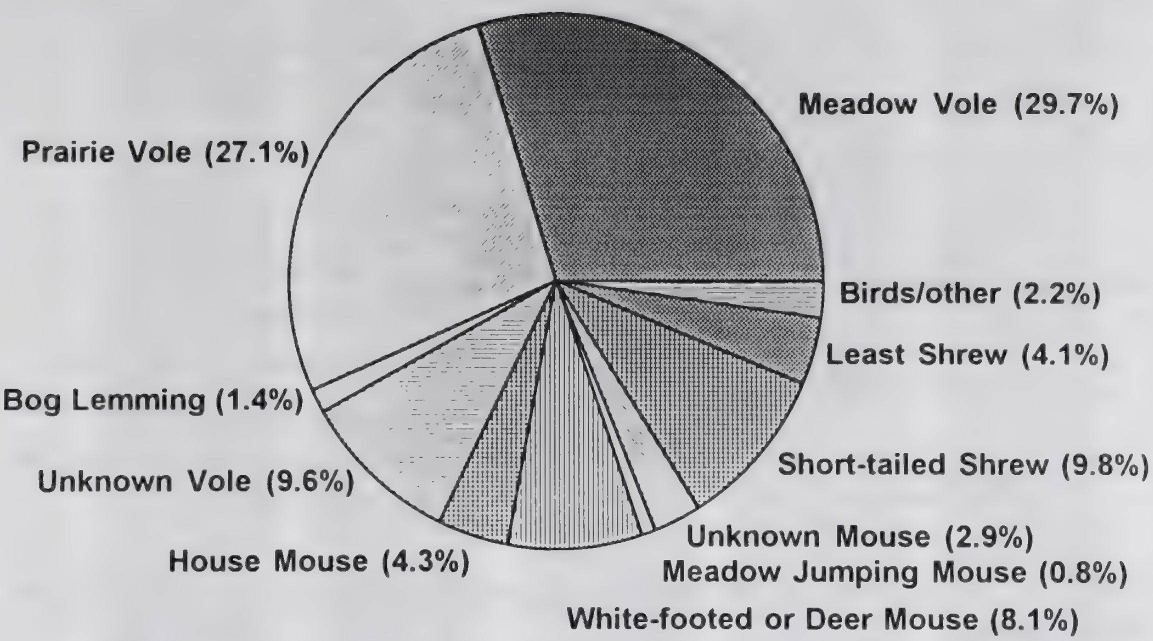

FIGURE 1. Relative Frequency of prey in barn owl pellets by species in Indiana from 1983 to 1987.

(*Agelaius phoeniceus*), starling (*Sturnus vulgaris*), rock dove (*Columba livia*), and other birds figured in the diet at less than 2% frequency.

Regional variation. Thirteen counties were chosen for evaluation of food habits as determined by total biomass of the pellet sampes ($N > 2.5$ kg). Vole use ranged from 31% to 80% total frequency and from 46% to 89% total biomass. Except in certain areas, the food habits of barn owls were similar across the State. Meadow vole was the most important prey species except in southwest Indiana (Daviess, Gibson, Perry, Spencer, and Sullivan Counties), where prairie voles were more important. In Floyd County, the meadow vole and prairie vole were of equal importance as barn owl food, but in Perry County, the meadow vole was not used at all.

The short-tailed shrew was 10% or more of the diet by both frequency and biomass in Floyd, Lake, Sullivan, Switzerland, and Washington Counties. Deer mice and white-footed mice composed 10% or more of the frequency and biomass in Daviess and Lake Counties. The Lake County sample also included more than 10% Norway rat.

Seasonal food habits. Collections of pellets from a family of barn owls in Spencer County were made weekly from January, 1986, to March, 1987 and were analyzed in monthly groups. Voles represented from 81% to 94% of the total biomass of the owls' diets (Figure 3). Prairie voles were the staple food source (46% frequency and 50% biomass). The only noteworthy seasonal change in diet was the lowered use of the meadow vole from April to June of 1986. Combined frequency of other species remained under 20% for all months.

The prey biomass of two families of barn owls from winter 1985-86 to winter 1986-87 in Orange County is represented in Figure 4. Vole use ranged from 55% to 83% of the total biomass. The meadow vole was the major food source and was utilized more in winter. Mice were more frequently used than either shrews or

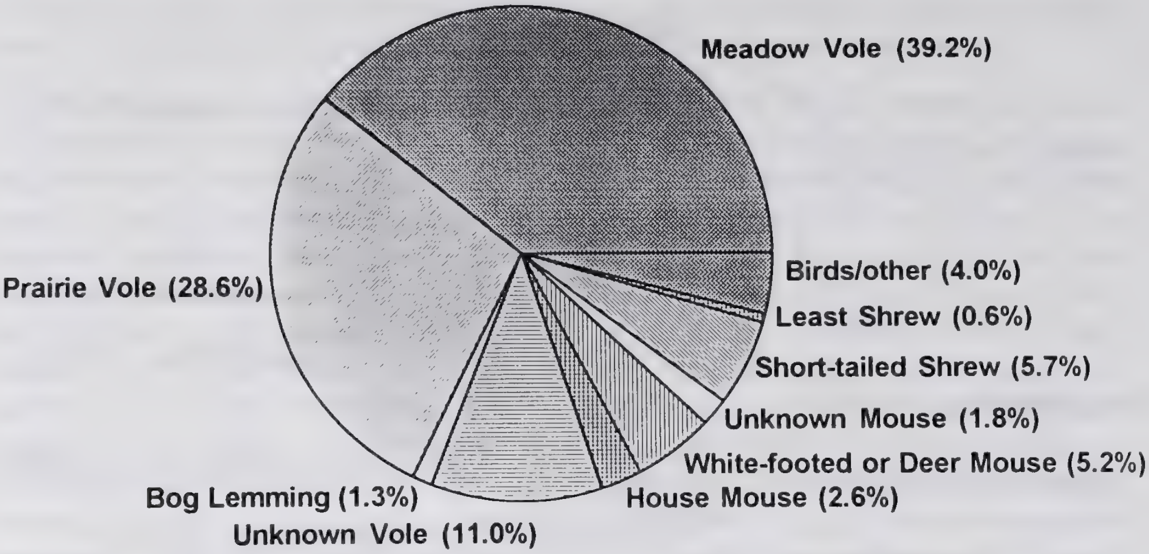

FIGURE 2. Relative biomass of prey in barn owl pellets by species in Indiana from 1983 to 1987.

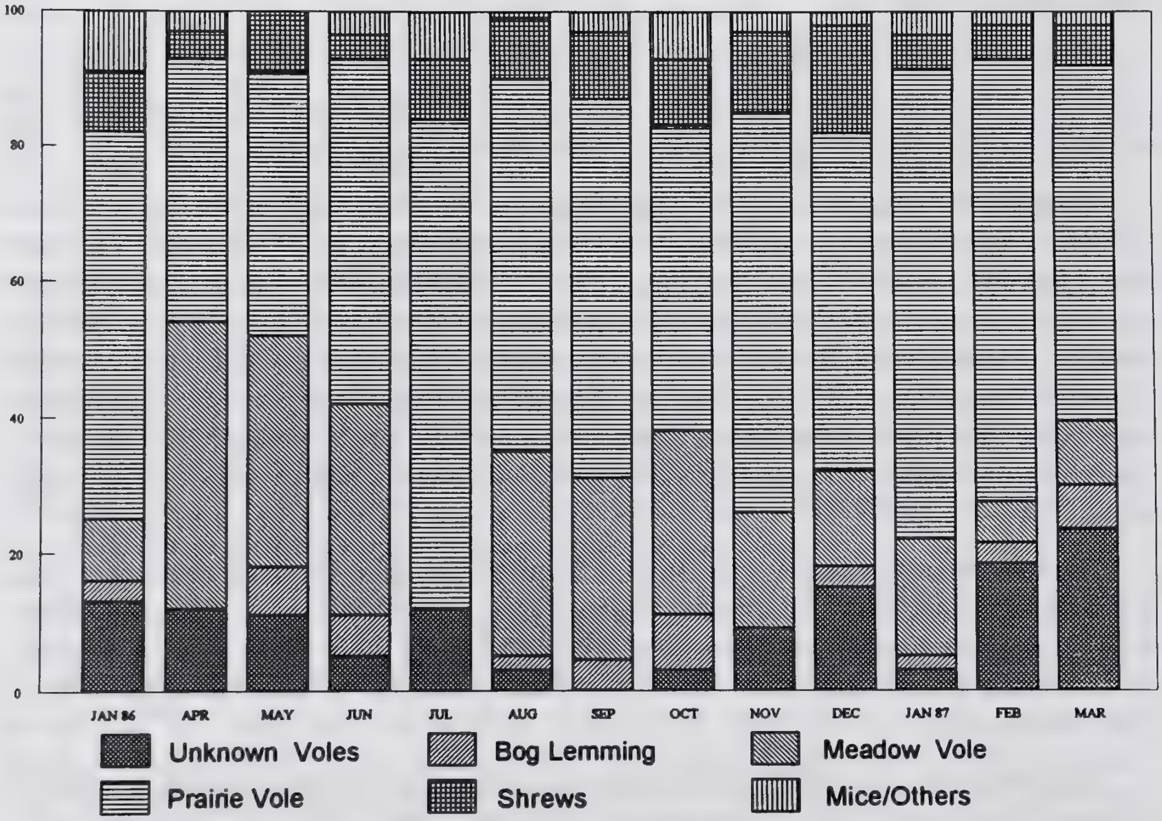

FIGURE 3. Monthly relative biomass of barn owl prey on the Spencer County area from January 1986 to March 1987.

prairie voles. During spring and fall, birds and unknown large mammals were more frequently fed upon.

Prey species distribution. No mammal species were found in pellets collected outside of the geographic ranges delineated by Hall (1981), but findings in counties where Mumford and Whitaker (1982) had not reported them are included

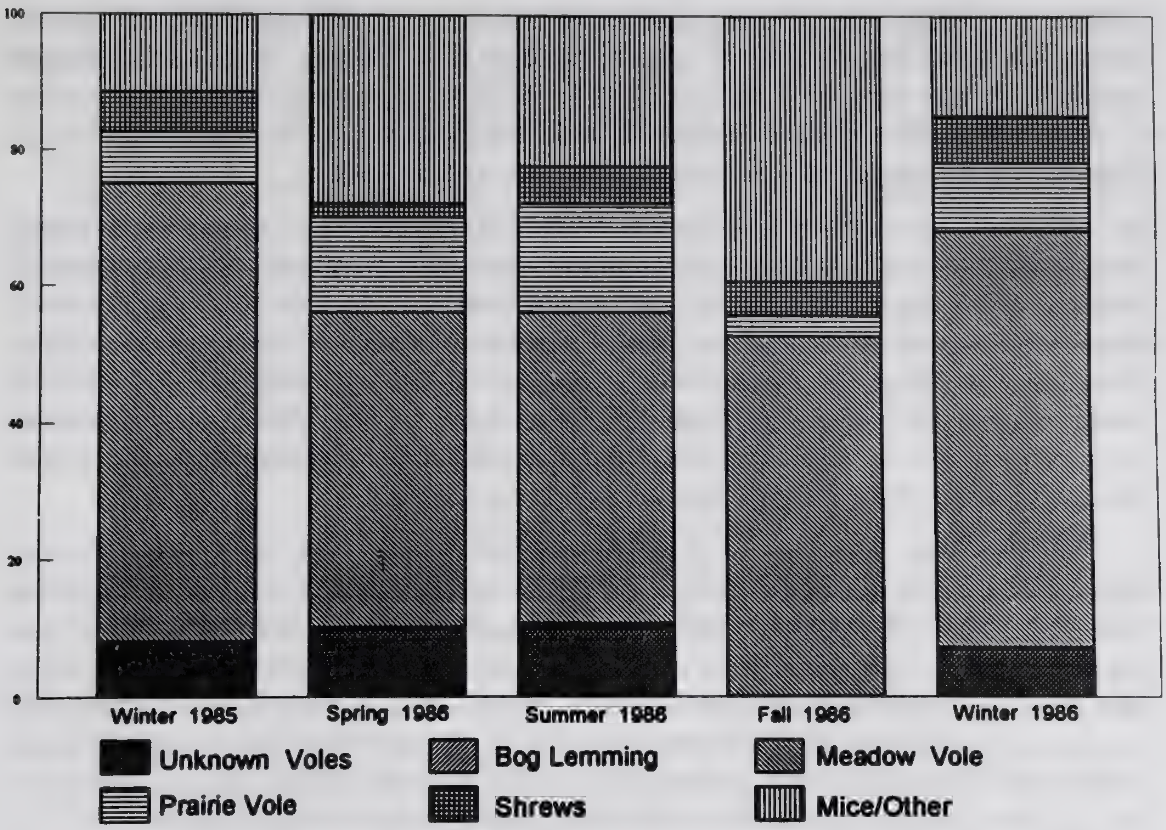

FIGURE 4. Seasonal relative biomass of Barn Owl prey on the Orange County area from December 1985 to March 1987.

here. The meadow vole was found in Daviess, Floyd, Lawrence, Orange, Spencer, Warrick, and Washington County pellets. The southern bog lemming was found in Gibson, Johnson, Orange, Owen, and Spencer County pellets. The meadow jumping mouse was taken by owls in Clark, Jennings, Perry, Sullivan, Switzerland, and Washington Counties. New records for the southeastern shrew include Jennings, Lake, and Orange Counties. The masked shrew was found in Orange and Switzerland County pellets. The location of the masked shrew in Orange County is noteworthy, because Cudmore and Whitaker (1984) had commented on its absence from south-central Indiana. The short-tailed shrew was found in Floyd County, the least shrew was found in Clark and Switzerland Counties, and a least weasel was found in Orange County.

DISCUSSION

Barn owl diets consisted of 70% to 90% voles in biomass on most of the areas studied. Of the 13 counties examined for comparison of regional food habits, two were somewhat different. The Lake County site is the northernmost record of a barn owl in Indiana in recent history (Iverson, 1988). Although Lake County is intensively farmed, the habitat near the roost site included a 2-mile strip of grass and brush bounded by a ditch. A single owl was observed there for one summer, and its diet reflected a lack of voles. Mice, shrews, rabbits, and rats made up a larger portion of its diet (67% by frequency) than was found elsewhere. Owls at an intensively farmed Daviess County site also depended more on mice and shrews (30% and 13% by frequency, respectively) than owls of other areas. Midwestern barn owls are dependent on marshes, thick grasslands, undergrazed pastures, old fields, hay fields, and fallow ground to hunt voles in (Colvin, 1985). Barn owl habitat in Ohio has decreased markedly due to a change from early century practices of crop rotation which included hay-fallow to modern intensive row crops (Colvin, 1985). The Lake and Daviess County barn owl diets were probably influenced by marginal habitat and/or low vole availability.

Prairie voles replaced the meadow vole as the most important prey in southwestern Indiana. These findings correlate with Mumford and Whitaker (1982), who found meadow voles scarce southwest of a line from Clark to Vigo County. Orange County is along this range overlap. Owl diets there changed from using more meadow voles (54% total vole frequency) in 1982 (Castrale, *et al.*, 1983) to using more prairie voles (73% total vole frequency) in 1986. This area may provide prey alternatives for barn owls during low meadow vole years, especially if population cycles of the two vole species are asynchronous.

The seasonal variation of meadow and prairie vole use in Spencer County may reflect a preference for the meadow vole due to its optimal size as suggested by Colvin (1985). If the owls prefer the lowland meadow vole to the upland (and smaller) prairie vole, then they may hunt lowland areas during wetter periods. The Spencer County owl diet during July, 1986, indicates a greater proportion of prairie voles and mice than meadow voles. Shifting habitat use during the fledging period and nearby mowing operations may have induced this change. However, comments on prey populations and habitat use can only be speculative.

In Indiana, the mean weight per prey item was 29.0 g. Colvin and McLean (1986) calculated mean weights per prey item in New Jersey and Ohio of 38 g and 30 g, respectively. From Rosenburg's data (1986), the author estimated a mean of 32 g per prey item for Virginia, and Marti (1974) found an average of 46 g in Colorado. The Virginia, Ohio, and Indiana study areas were marginal in habitat compared to the New Jersey and Colorado areas. If barn owls of other areas are feeding on larger food items, then the birds of Indiana and Ohio are feeding less efficiently and are at greater risk during periods of low vole availability.

Barn owls appear to require voles in the Midwest to survive. They need a continuous food supply for at least 18 weeks in order to reproduce successfully (Otteni, *et al.*, 1972). Glue (1967) found that owl diets change from voles to less preferred prey, when thick stands of grass were cut or grazed. Thus, the owl-vole-grassland concept is fundamental for proper management of the common barn owl (Colvin and McLean, 1986). The minimum amount of grassland required to sustain a breeding pair of barn owls varies from 97 hectares in Virginia (Rosenburg, 1986) to 39 hectares within a 288 m radius in Ohio (Colvin, personal communication). However, Colvin suggests that even in the most ideal habitat, owls may not survive in a low prey year. Future research should attempt to estimate the minimum required habitat to sustain Barn Owls during a low ebb of the prey cycle in the Midwest.

The barn owls of Indiana are restricted primarily to the southern half of the State (Iverson, 1988). The reason for this is suspected to be both the avoidance of northern temperatures and snowfall and the more abundant small farms, abandoned farms, grassland-reclaimed coal mines, and idle land in the south. The region of meadow-prairie vole overlap may also provide a more stable food supply. Recommendations for preserving the common barn owl in Indiana as a nesting species must include the maintenance of large areas of grassland, marsh, or hayfield.

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MICROTUS XANTHOGNATHUS AND *SYNAPTOMYS BOREALIS* IN THE LATE PLEISTOCENE OF SOUTHERN INDIANA

Ronald L. Richards
Indiana State Museum
Department of Natural Resources
202 North Alabama Street
Indianapolis, Indiana 46204

INTRODUCTION

Arvicoline rodents and shrews are often abundant in Late Pleistocene faunal deposits, where they usually display a greater species diversity than in modern faunas (Graham, 1976). Because the arvicoline rodents and shrews recovered from Late Pleistocene sites are, for the most part, living today, knowledge of their modern habitats and environmental tolerances suggest possible habitats and environments during deposition. The extralimital occurrence of *Phenacomys* cf. *P. intermedius* (heather vole) and *Clethrionomys gapperi* (southern red-backed vole) (Richards, 1986) supported pollen spectra that indicated boreal woodlands in southern Indiana during the Late Pleistocene. The recovery of two fossil arvicolines (*Microtus xanthognathus*, yellow-cheeked vole, and *Synaptomys borealis*, the northern bog lemming) from stratified deposits for the first time in Indiana provides new information on biotic community transition in the Late Pleistocene and Early Holocene of Indiana.

Today, *Microtus xanthognathus* occurs in east-central Alaska eastward to the Northwest Territories and south through central Alberta, northern Saskatchewan, and northern Manitoba (Hall, 1981; Figure 1). This large vole is local in occurrence and undergoes extreme fluctuation in population size (Guilday, Martin, and McCrady, 1964; Guilday, Parmalee, and Hamilton, 1977). Feeding primarily on horsetails, lichens, and grasses, the yellow-checked vole occurs in well-drained upland woods and in moist valleys; it constructs runways from its burrow to sphagnum bogs (Banfield, 1974; Guilday, Parmalee, and Hamilton, 1977; Wolff and Lidicker, 1980). It prefers at least partially forested habitat with a thick humus or bryophyte cover (Wolff and Lidicker, 1980). Guilday, *et al.* (1977) related that "a thin boreal forest dominated by spruce and jackpine with a ground covering of heaths and sphagnum would accommodate this vole," and that it apparently did not occur in grasslands.

Microtus xanthognathus molars are readily recognized by their large size, an occlusal pattern like that of *M. pennsylvanicus*, and a distinctive absence of cement in the third lateral reentrant of M3 (Guilday, 1982; Guilday and Bender, 1960; Guilday, Parmalee, and Hamilton, 1977; Hallberg, *et al.*, 1974; Rhodes, 1984; Semken, 1984). Fossils have been reported from at least 20 Late Pleistocene localities and one Holocene locality in 13 other States (Figure 1). The fossils recovered from Megenity Peccary Cave, Indiana, occurred 2132 km (1325 miles) south of the nearest living population in Manitoba.

Today, *Synaptomys borealis* occurs throughout much of Canada and Alaska with its range extending south into Washington, Idaho, Montana, Minnesota, Maine, and New Hampshire (Hall, 1981; Figure 2). It occupies the boreal forest region, occurring primarily in sphagnum/spruce bogs but also in thick, mossy spruce woods, wet subalpine meadows, and alpine tundra (Banfield, 1974). Lower molars of *Synaptomys borealis* are separated from those of *S. cooperi* (southern bog lemming) by the lack of labial triangles (Semken, 1984). Upper molars of the two species are very similar. *Synaptomys borealis* fossils are known from at least 21 Late (and one Middle) Pleistocene localities in 11 other States (Figure 2).

DESCRIPTIVE PALEOZOOLOGY

Vertebrate nomenclature used in this report follows Banks, *et al.* (1987). Abbreviations used are as follows: L, R, left, right; M1, M2, M3, m1, m2, m3, upper and lower molars one through three, respectively; MNI, minimum number of individuals; BP, Before Present (AD 1950).

One Indiana Late Pleistocene locality (Megenity Peccary Cave) produced fossils of both *Microtus xanthognathus* and *Synaptomys borealis* while work at a second locality (Prairie Creek Site) produced only *M. xanthognathus*.

LOCALITY 1.

Location. Megenity Peccary Cave (Taswell Quad.), Crawford County, Indiana.

Materials. *Microtus xanthognathus*: 32 partial skulls; 32L, 34R dentaries; 34L, 34R M1; 35L, 35R M2; 38L, 35R M3; 33L, 34R m1; 33L, 34R m2; and 32L, 35R m3 (MNI = 38; Figure 3). *Synaptomys borealis*: 5L, 8R dentaries; 11L, 11R m1; 13L, 11R m2; and 12L, 11R m3 (MNI = 13). Postcranial material of both species has been recovered but not separated.

Occurrence. The materials were recovered from a laminated clay bank in the "Microfauna Room", entered by a 4.9 m drop, 44.2 m from the present entrance. *Microtus xanthognathus* and *Synaptomys borealis* both occurred in Units C and D (respectively 30-40 and 40-50 cm below the surface).

Important associations. Extralimital species: *Sorex arcticus* (arctic shrew), *Clethrionomys gapperi*, and *Phenacomys* cf. *P. intermedius*.

Comments. Excavation units (0.5 m^2) were separated at ca 10 cm intervals along natural bedding planes. Most units produced extensive microfaunas dominated by ranid frogs. Units A (uppermost) and B included arvicolines and shrews that reside in Indiana today (*Microtus pinetorum/ochrogaster*, the pine/prairie vole, *Sorex cinereus*, masked shrew, and *Blarina brevicauda*, the short-tailed shrew). Unit C contained the same resident taxa as well as *Microtus pennsylvanicus* (meadow vole), *Synaptomys cooperi*, and *Sorex fumeus* (smoky shrew). Extralimital species included *Clethrionomys gapperi* and *Sorex arcticus*. *Synaptomys borealis* and especially *Microtus xanthognathus* were most abundant. A 20.04 gm sample of selected *M. xanthognathus* limb bones and vertebrae (supplemented with some *M. pennsylvanicus* elements) from Unit C produced an AMS radiocarbon age of 14,125 ± 140 BP (Beta-31905; ETH-5525). Unit D was also dominated by *Synaptomys borealis* and *Microtus xanthognathus*. *Phenacomys* cf. *P. intermedius* was the only other extralimital species, and *Microtus pennsylvanicus*, *Synaptomys cooperi*, and *Sorex cinereus* were the resident species. Sparsely sampled unit E produced only *Microtus pennsylvanicus* and *Synaptomys* sp. Megenity Peccary

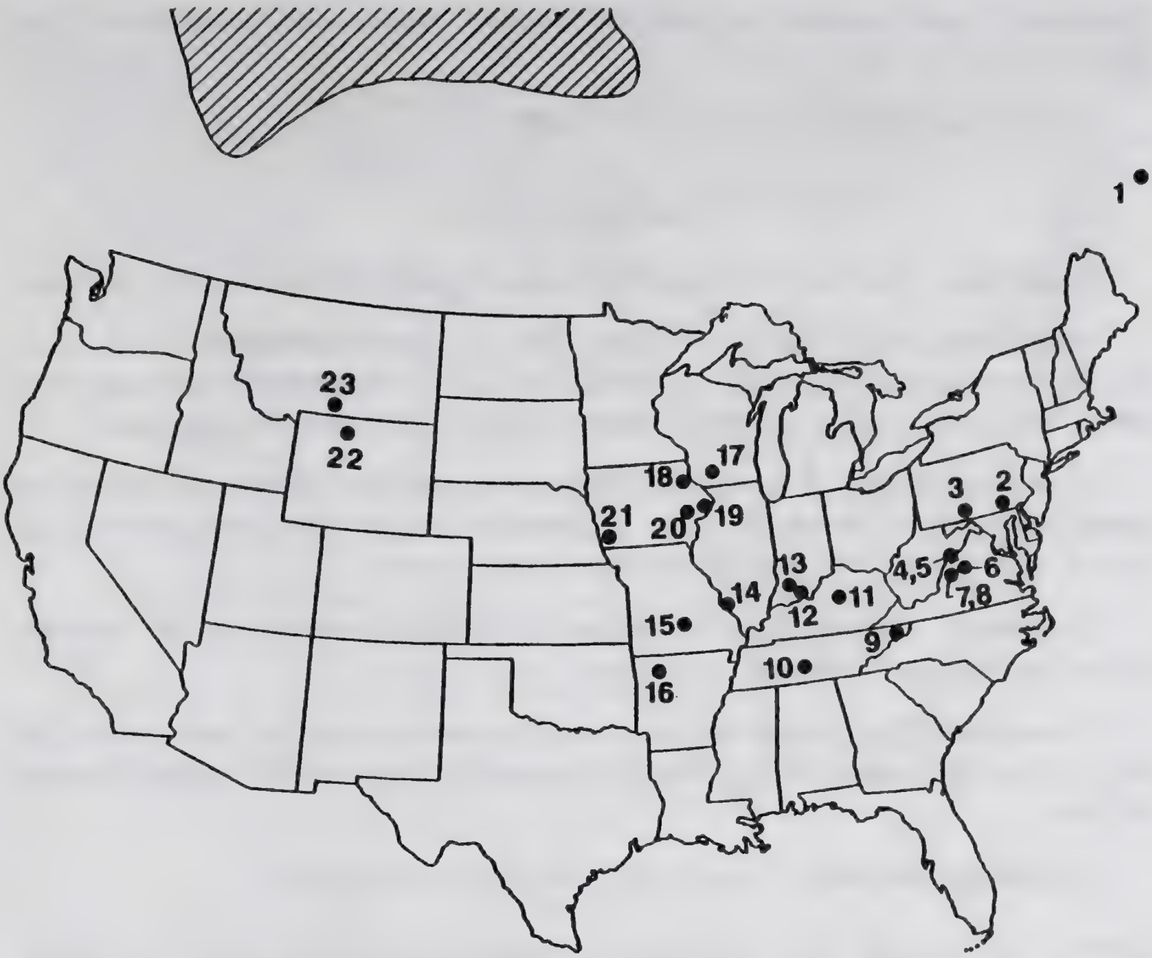

FIGURE 1. Late Pleistocene extralimital occurrence of *Microtus xanthognathus*. Southern part of the modern range (hatched) after Hall (1981). 1. St. Elzear Cave, Quebec, Canada (Lasalle, 1984). 2. Bootlegger Sink, York County, Pennsylvania (Guilday, Hamilton, and McCrady, 1966). 3. New Paris No. 4, Bedford County, Pennsylvania (Guilday and Bender, 1960; Guilday, Martin, and McCrady, 1964). 4. Eagle (Eagle Rock) Cave, Pendleton County, West Virginia (Guilday, 1971; Guilday and Hamilton, 1973). 5. New Trout Cave, Pendleton County, West Virginia (Grady, 1984; Grady and Garton, 1981). 6. Natural Chimneys, Augusta County, Virginia (Guilday, 1962; Guilday and Bender, 1960). 7. Clark's Cave,Bath County, Virginia (Guilday, Parmalee, and Hamilton, 1977). 8. Back Creek Cave No. 2, Bath County, Virginia (Guilday, Parmalee, and Hamilton, 1977). 9. Baker Bluff Cave, Sullivan County, Tennessee (Guilday, Hamilton, Anderson, and Parmalee, 1978). 10. Cheek Bend Cave, Maury County, Tennessee (Parmalee and Klippel 1981a, b). 11. Welsh Cave, Woodford County, Kentucky (Guilday, Hamilton, and McCrady, 1971). 12. Megenity Peccary Cave, Crawford County, Indiana (this report). 13. Prairie Creek Site, Daviess County, Indiana (this report). 14. Meyer Cave, Monroe County, Illinois (Parmalee, 1967). 15. Bat Cave, Pulaski County, Missouri (Hawksley, Reynolds, and Foley, 1973). 16. Peccary Cave, Newton County, Arkansas (Hallberg, Semken, and Davis, 1974; Semken, 1984). 17. Moscow Fissure, Iowa County, Wisconsin (Foley, 1984). 18. Elkader l.f., Clayton County, Iowa (Graham and Mead, 1987; Woodman, 1982). 19. Eagle Point l.f., Clinton County, Iowa (Rosenberg, 1983). 20. Conklin Quarry, Johnson County, Iowa (Baker, *et al.*, 1986). 21. Waubonsie l.f., Mills County, Iowa (Hallberg, Semken, and Davis, 1974; Rhodes, 1984; Rhodes and Semken, 1986). 22. Prospects Shelter, Bighorn County, Wyoming (Walker, 1987). 23. False Cougar Cave, Carbon County, Montana (Holocene; Graham, Wilson, and Graham, 1987).

Cave is still under excavation, with all material reposited at the Indiana State Museum.

Published record. Richards (1988, 1993).

LOCALITY 2.

Location. Prairie Creek Site (Washington Quad.), Daviess County, Indiana.

Materials. *Microtus xanthognathus.* (Zone D, Late Pleistocene): 2L M1, lacking anterior loops (Units 2460 and 2462); and L M3, lacking anterior loop (Unit 2460). Some postcranial material is questionably referred to this species.

Occurrence. Zone D represents alluvial redeposition of bones and sediments flushed from a Late Pleistocene lake bed that had accumulated at approximately 14,010 ± 140 B.P. (DIC-234; P.J. Munson, pers. comm.).

Important associations. An extensive fauna is under study by Munson, Parmalee, Holman, Richards, and others.

Comments. The present *Microtus xanthognathus* material, and most of the fauna, is on file at the Glenn A. Black Laboratory of Archaeology in Bloomington, Indiana.

Published Records. Tomak (1975, 1982; Richard, 1993).

DISCUSSION

Microtus xanthognathus, *Synaptomys borealis*, *Phenacomys intermedius*, and *Sorex arcticus* are characteristic northern elements of early post-Wisconsinan cave faunas in the central and southern Appalachians (e.g., Bootlegger Sink and New Paris No. 4, Pennsylvania; Eagle Cave, West Virginia; Clark's Cave and Natural Chimneys, Virginia; Baker Bluff Cave and Robinson Cave, Tennessee; and Welsh Cave, Kentucky; Guilday and Hamilton, 1973). Other cave faunas outside the Appalachian region (e.g., Bat Cave and Crankshaft Cave, Missouri; and Peccary Cave, Arkansas) have also produced various suites of northern extralimital species, similarly tempered by Late Pleistocene environmental gradients that relocate progressively fewer boreal taxa toward the south (Guilday, Hamilton, Anderson and Parmalee, 1978) and presumably more distant in all directions from the Appalachians. The arvicoline and shrew taxa identified from the Microfauna Room of Megenity Peccary Cave display the strong boreal affinities of those recovered from central and southern Appalachian Late Pleistocene faunas. Other taxa that frequently occur in Appalachian Late Pleistocene faunas, but have not been recovered in Indiana, include *Microtus chrotorrhinus* (rock vole), *Dicrostonyx hudsonius* (Labrador collared lemming), and *Sorex palustris* (northern water shrew).

Most Late Pleistocene faunas in the eastern U.S. also include taxa indicative of open areas (e.g., *Geomys bursarius*, plains pocket gopher, *Spermophilus tridecemlineatus*, the thirteen-lined ground squirrel, and *Microtus pennsylvanicus).* These faunas usually include species that co-inhabited a region at the time of deposition, but that occupy segregated ranges today (e.g., *Microtus xanthognathus* and *Blarina brevicauda* in the Megenity Peccary Cave paleofauna). These seem-

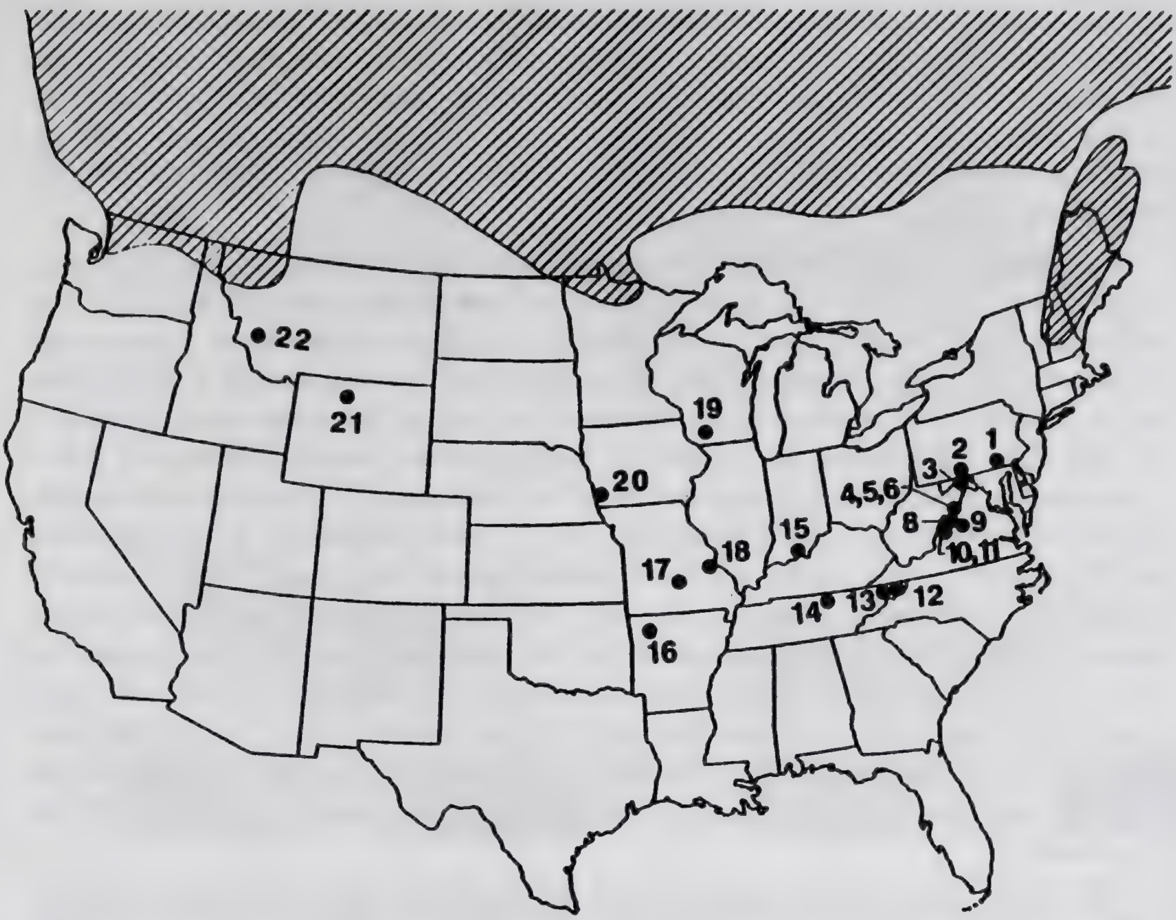

FIGURE 2. Late Pleistocene extralimital occurrence of *Synaptomys borealis*. Southern part of the modern range (hatched) after Hall (1981). 1. Bootlegger Sink, York County, Pennsylvania (Guilday, Hamilton, and McCrady, 1966). 2. New Paris No. 4, Bedford County, Pennsylvania (Guilday, Martin, and McCrady, 1964). 3. Cumberland Cave, Allegany County, Maryland (Middle Pleistocene; Gidley and Gazin, 1938; Kurten and Anderson, 1980). 4. Eagle (Eagle Rock) Cave, Pendleton County, West Virginia (Guilday and Hamilton, 1973). 5. Hoffman School Cave, Pendleton County, West Virginia (Guilday and Hamilton, 1978). 6. Mandy Walters Cave, Pendleton County, West Virginia (Guilday and Hamilton, 1978). 7. NOT SHOWN ON MAP: Bowden Cave, county not available, West Virginia (Guilday, Parmalee, and Hamilton, 1977). 8. Straight Canyon Fissure, Highland County, Virginia (Jones, *et al.*, 1984). 9. Natural Chimneys, Augusta County, Virginia (Guilday, 1962). 10. Clark's Cave, Bath County, Virginia (Guilday, Parmalee, and Hamilton, 1977). 11. Back Creek Cave No. 2, Bath County, Virginia (Guilday, Parmalee, and Hamilton, 1977). 12. Guy Wilson Cave, Sullivan County, Tennessee (Corgan, 1976; Guilday, Hamilton, and Parmalee, 1975). 13. Baker Bluff Cave, Sullivan County, Tennessee (Guilday, Hamilton, Anderson, and Parmalee, 1978). 14. Robinson Cave, Overton County, Tennessee (Guilday, Hamilton, and McCrady, 1969). 15. Megenity Peccary Cave, Crawford County, Indiana (this report). 16. Peccary Cave, Newton County, Arkansas (Semken, 1984). 17. Bat Cave, Pulaski County, Missouri (Hawksley, Reynolds, and Foley, 1973). 18. Crankshaft Cave, Jefferson County, Missouri (Parmalee, Oesch, and Guilday, 1969). 19. Moscow Fissure, Iowa County, Wisconsin (Foley, 1984). 20. Craigmile l.f., Mills County, Iowa (Rhodes, 1984; Rhodes and Semken, 1986). 21. Prospects Shelter, Bighorn County, Wyoming (Walker, 1987). 22. Morse Creek #1, Granite County, Montana (Graham, Wilson, and Graham, 1987).

ingly anomalous associations of taxa are thought to have been structured by more equable Late Pleistocene climates (climates with reduced seasonal temperature extremes) that allowed individual taxa to reorganize their distribution according to their own tolerances along changing environmental gradients, producing unique biotic communities (Graham, 1976, 1985a, 1985b; Graham and Mead, 1987; King and Graham, 1981).

Guilday (1971) and Guilday, Parmalee, and Hamilton (1977) suggested that *Microtus xanthognathus* is a good indicator of parklands composed of thin, open coniferous forest. Hallberg, *et al.* (1974) found the same boreal associations with *M. xanthognathus* at Peccary Cave, Arkansas that Guilday did at Appalachian sites, but they also recovered more temperate fauna (e.g., *Sciurus niger*, fox squirrel, and *Microtus pinetorum*) suggesting higher winter temperatures and some deciduous vegetation. They contended that the presence of *M. xanthognathus* was indicative of conditions more analogous to the open parklands of the southern boreal forest than the northern boreal forest-tundra transition. The presence of temperate deciduous woodland taxa (e.g., *Blarina brevicauda* and *Synaptomys cooperi*) associated with *M. xanthognathus* at Megenity Peccary Cave suggests a good analogy with the southern boreal forest/parkland, when boreal and temperate forest taxa were reorganized into unique communities. Though *M. xanthognathus* occupies the northern boreal forest today, it may not have inhabited a clearly analogous environment in the reorganized communities of the Late Pleistocene.

Microtus xanthognathus has not been reported from sites older than Wisconsinan age (Guilday, Parmalee, and Hamilton, 1977). Associated radiocarbon dates include 11,300 ± 1,000 BP (New Paris No. 4, Pennsylvania), 12,950 ± 550 BP (Welsh Cave, Kentucky), 14,010 ± 140 B.P. (Prairie Creek, Indiana), 14,125 ± 140 B.P. (Megenity Peccary Cave, Indiana), and 19,100 ± 850 BP to 10,560 ± 220 BP (Baker Bluff Cave, Tennessee) (Graham and Mead, 1987). According to the concept of shifting environmental gradients produced by the advance and recession of Wisconsinan ice, *M. xanthognathus* should have populated southern localities later and abandoned them earlier than it did in more northern Appalachian regions. More dates associated with key strata are needed before it will be possible to define and map population movement of any species during the Quaternary. *Microtus xanthognathus* was one of the first boreal voles to disappear from the mid-Appalachian mammalian fauna, as early post-Wisconsinan warming allowed closed-canopy forests (Guilday and Hamilton, 1978; Guilday, Parmalee, and Hamilton, 1977).

Today, *Synaptomys borealis* inhabits the boreal forest region, and *S. cooperi* inhabits the mixed forest to the south; the two are nearly allopatric, with a narrow area of sympatry in portions of southeastern Manitoba, southwestern Ontario, northwestern Minnesota, eastern Quebec, Maine, and New Hampshire (Hall, 1981). Both species are found in the same deposits in many Late Pleistocene localities as far south as Peccary Cave, Arkansas; this fossil association suggests that environmental conditions during their deposition may have been similar to those in their area of sympatry today (Guilday, Martin, and McCrady, 1964). *Synaptomys cooperi* replaced *S. borealis* in the central Appalachians around 11,000 BP (Guilday, Parmalee, and Hamilton, 1977). Both species coexisted during the deposition of Units C and D at Megenity Peccary Cave, but neither was recorded in succeeding Units B and A.

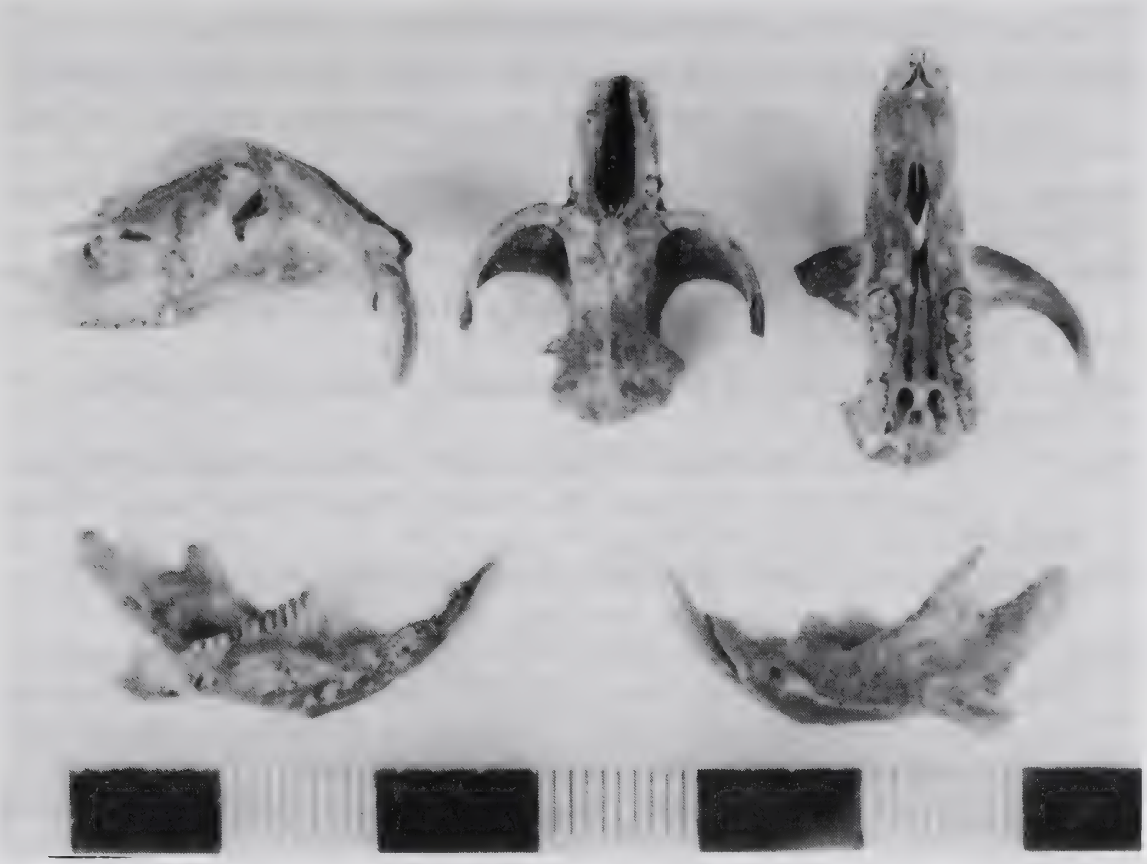

FIGURE 3. Three fragmented crania and two L dentaries of *Microtus xanthognathus* from unit C, Microfauna Room, Megenity Peccary Cave, Indiana. Scale in mm and cm.

The extralimital taxa from Units C and D of Megenity Peccary Cave (*Microtus xanthognathus*, *Synaptomys borealis*, *Phenacomys* cf. *P. intermedius*, *Clethrionomys gapperi*, and *Sorex arcticus*) are found together today in central and northern Alberta east to Manitoba. Other species recovered from those units (*Blarina brevicauda* and *Synaptomys cooperi*) presently occupy more temperate areas. Units C and D accumulated with taxa that do not co-exist today, suggesting deposition in an environment that has no modern analog. Units C and D appear to have formed in a thin, spruce-dominated woodland that included some temperate elements existing in a cool, moist, more equable climate (i.e., reduced temperature extremes). Units A and B were apparently deposited after postglacial warming and migration north of deciduous forests.

ACKNOWLEDGMENTS

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QUATERNARY OCCURRENCE OF THE FISHER, *MARTES PENNANTI*, IN INDIANA

Ronald L. Richards
Indiana State Museum
Department of Natural Resources
202 North Alabama Street
Indianapolis, Indiana 46204

INTRODUCTION

The fisher (*Martes pennanti*) is a relatively solitary carnivore that feeds primarily upon the snowshoe hare, mice, the porcupine, birds, carrion, and occasionally other carnivores and berries (Burt and Grossenheider, 1964; Powell, 1982). It especially prefers conifer forests but also occurs in mixed conifer/hardwood and open hardwood forests that maintain continuous overhead cover (Powell, 1982). The fisher is typically found in dense lowland/wetland forests, where the canopy is high. It avoids nonforested areas (Powell, 1982). The fisher is distributed from northern British Columbia across Canada south of Hudson Bay to southeastern Quebec; it also occurs in the northwestern U.S., the Sierra Nevada and northern Rocky Mountains, the Great Lakes region, and New England (Anderson, 1970; Hall, 1981).

Presently the fisher does not occur in Indiana, but historic records document its presence prior to 1859. Records exist for Posey (1833), Wayne (1820), Hamilton (1859), and Allen (1811) counties (Anonymous, 1906; Mumford, 1969; Plummer, 1844; von Wied, 1841). The fisher was last seen in northern Illinois in the 1850's (Kennicott, 1855).

In more recent years, fisher remains have been recovered from natural and culturally derived bone accumulations. In 1946, a skull fragment with two molars was found "at the site of an old Indian village" in Ohio County, Indiana (Kirkpatrick and Conaway, 1948). A few years later a partial right dentary with a canine tooth was found in a dunes blowout in what is probably Porter County (Rand and Rand, 1951). Accumulating fisher records (Figure 1) were summarized by Hahn (1909), Lyon (1936), and Mumford (1969). Martin (1986) recently identified fisher bones representing a minimum of two individuals (2 R maxillae; 2 L, 1 R dentaries; L c; axis; L innominate) among the faunal remains at Fort Ouiatenon, an eighteenth century trading post in Tippecanoe County. Recovery of additional fisher material has led to the present report.

DESCRIPTIVE PALEOZOOLOGY

Verebrate nomenclature used in this report follows Banks, *et al.* (1987). Abbreviations used are as follows: L, R, left, right; I,C,P,M,i,c,p,m, upper, and lower incisor, canine, premolar, and molar, respectively; and B.P., Before Present (A.D. 1950).

Fisher remains have been identified from three late Pleistocene localities in Harrison, Crawford, and Daviess Counties (Figures 1-3).

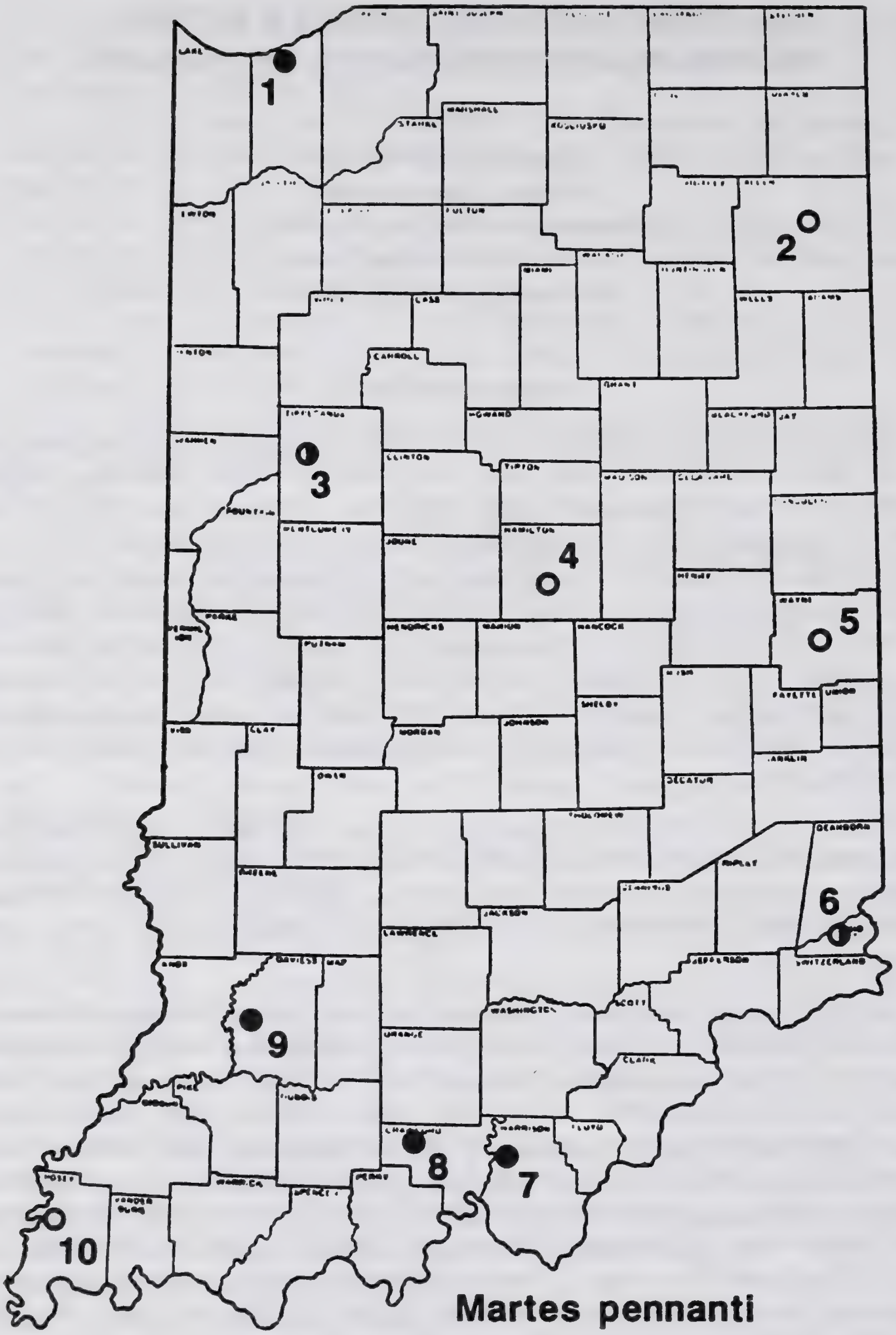

FIGURE 1. Late Pleistocene, Holocene, and historic records of the fisher (*Martes pennanti*) in Indiana. Solid circles represent paleontological localities; eclipsed circles represent archaeological sites, and hollow circles represent historic records. Sites identified include: 1) Dunes, probably Porter Co. (Rand and Rand, 1951); 2) Fort Wayne trading post, Allen County, 1811 (Mumford, 1969); 3) Fort Ouiatenon, Tippecanoe County (Martin, 1986); 4) Fur dealer, Hamilton County, 1859 (Anonymous, 1906); 5) Wayne County, 1820 (Plummer, 1844); 6) Indian village site, Ohio County (Kirkpatrick and Conaway, 1948); 7) King Leo Cave, Harrison County; 8) Megenity Peccary Cave, Crawford County; 9) Prairie Creek Site, Daviess County; 10) New Harmony, Posey County, 1833 (von Wied, 1841).

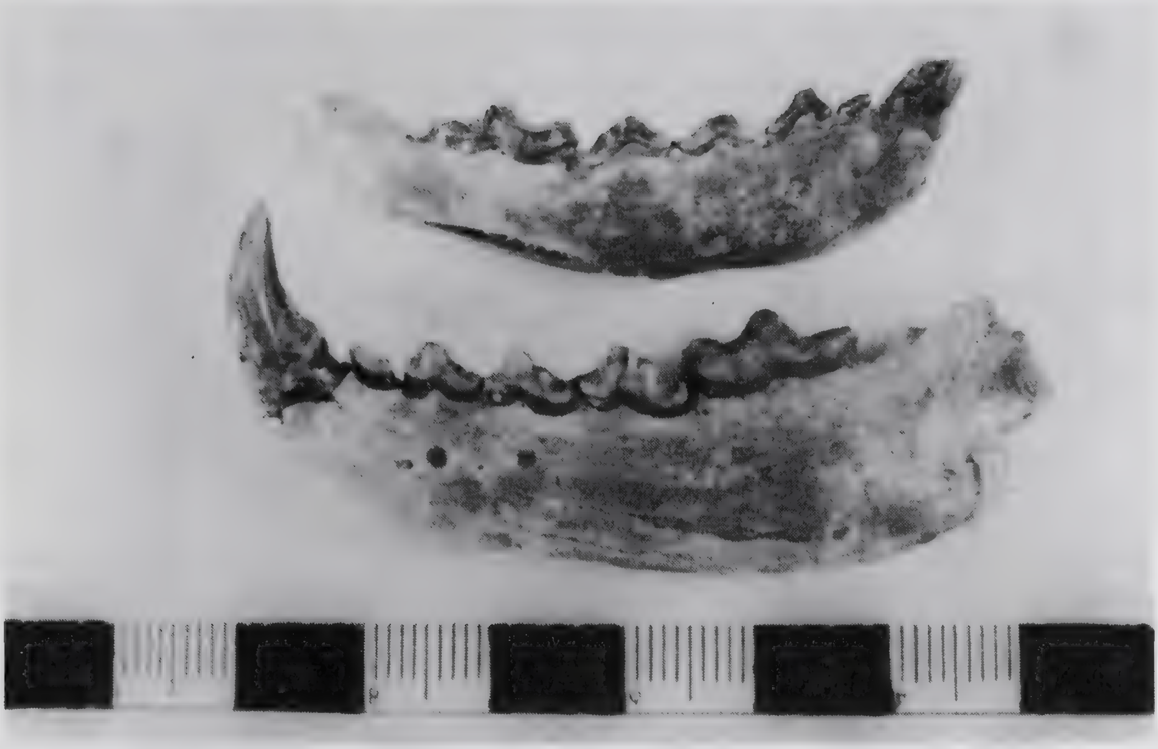

FIGURE 2. Left male (below) and right female dentaries of the fisher (*Martes pennanti*), Megenity Peccary Cave, Crawford County, Indiana. Scale in millimeters and centimeters.

LOCALITY 1

King Leo Cave (Depauw Quadrangle) Harrison County, Indiana.

Materials. Incomplete skeleton of a large male: partial L dentary with m1 (heel) and m2; L c: partial R dentary with c, pl and p2; R m1; R m2; C root; axis; 2 cervical, 3 thoracic, 1 lumbar, and 5 caudal vertebrae; 11 fragmented ribs; manubrium; 5 sternabrae; L radius; fibula, proximal end; R calcaneum; R astragalus; L, R magna; R scapholunar; cuboid; 13 metapodials; 4 proximal, 5 medial, 14 distal phalanges; patella; 5 sesamoids; miscellaneous fragments (Figure 3B).

Occurrence. Bones occurred within a 10-20 cm thick silt deposit on the bedrock floor of an abandoned stream channel deep within the cave (probable old entrance, now closed, 77m away).

Important associations. Extinct: *Bootherium bombifrons*, Harlan's muskox. Extralimital: *Clethrionomys gapperi*, southern red-backed vole; *Phenacomys* cf. *P. intermedius*, heather vole.

Comments. Deposit is undated, but presence of extinct and extralimital boreal taxa indicate Late Pleistocene age. Many of the small mammal bones in the deposit are splintered and crusted with a white, chalky mass, probably representing the scat of a carnivore, possibly fisher. The cave fauna is reposited at the Indiana State Museum.

Published records. Richards, 1984, 1986, 1991.

LOCALITY 2

Megenity Peccary Cave (Taswell Quadrangle) Crawford County, Indiana.

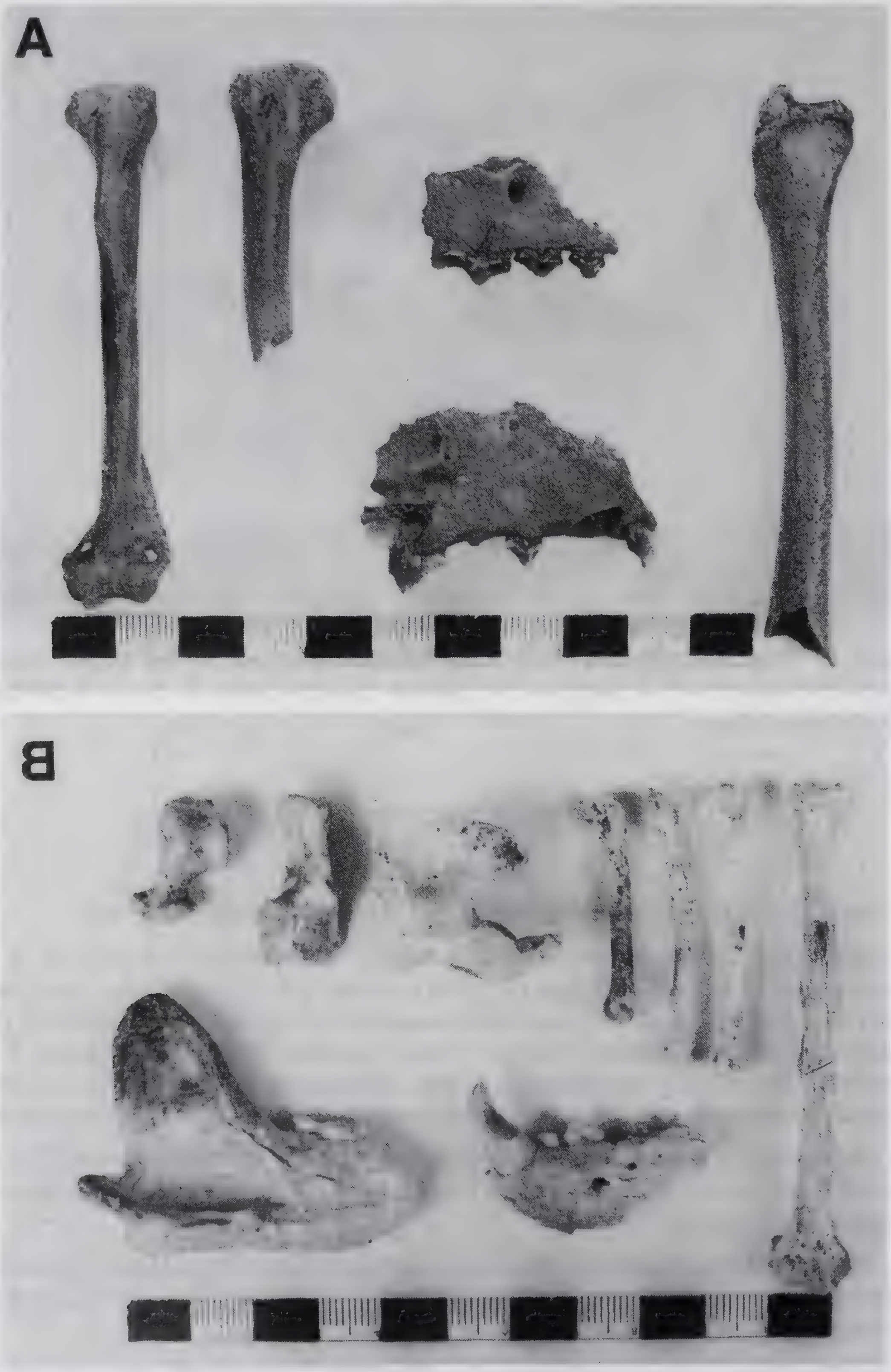

FIGURE 3. Selected Late Pleistocene and Holocene remains of the fisher (*Martes pennanti*). Scale in millimeters and centimeters. **A.** Prairie Creek Site, Daviess County, Indiana (from left to right): L femur, L maxilla (top), L maxilla + premaxilla; L humerus, proximal end; R humerus. Left humerus is of Holocene age. R humerus is female; all other elements are male, Late Pleistocene age. **B.** King Leo Cave, Harrison County, Indiana; all from one Late Pleistocene male; top row (left to right): L radius, 3 metapodials, axis, R calcaneum, R astragalus; bottom row: partial R dentary, partial L dentary.

Materials. Unit 18B: L dentary with c-m1 (male), lacking posterior portion of ramus. Test trench: R dentary with c-m1 (female), lacking posterior and inferior portions of ramus (Figure 2).

Occurrence. Both elements recovered from floor sediments in the "Peccary Room" below a 4.6 m drop, 42.7 m from the present entrance. Male jaw occurred in sediments of Unit 18B (10-20 cm below surface), in association with two skeletons of an extinct peccary. Female jaw from the test trench also was probably associated with peccary.

Important associations. Extinct: *Platygonus compressus*, flat-headed peccary. Extralimital: Unit 18B and B-level strata of adjacent units: *Geomys bursarius* (Plains pocket gopher); *Phenacomys* cf. *P. intermedius* (heather vole).

Comments. Radiocarbon dating of peccary bone collagen (Units 17B, 18B, 19B) indicated an age of 30,880 ± 500 B.P. (Beta-24801). Extralimital species suggest a mixture of boreal forest and open grassland during deposition of those units. Megenity Peccary Cave is currently under excavation and all materials are reposited at the Indiana State Museum.

Published records. Richards, 1987, 1988.

LOCALITY 3

Prairie Creek Site (Washington Quadrangle) Daviess County, Indiana.

Materials. Zone D, Late Pleistocene: L maxilla with P2-P4 (male, 794/1); L maxilla + premaxilla with I3, P2 and P4 (male, 513/1); R C (male, 513/4); R humerus (female, 1497/1); L femur (male, 513/2). Zone C, Late Pleistocene/ Holcene mixture: L M1 (218/1); L c (male, 237/1). Zone B, Holocene: L dentary, condyle area (male, 214/2); L humerus, proximal end (male, 211/3); R calcaneum (male, 229/1; Figure 3A). Additional material is questionably referred to fisher.

Occurrence. Zone D represents alluvial redeposition of bones and sediments flushed from a Late Pleistocene lake bed that had accumulated 14,000-15,000 years before present, with an available radiocarbon date of 14,010 ± 140 B.P. (P.J. Munson, pers. comm). Zone B represents Holocene accumulation (approximately 4,140-2,880 B.P.) in the bed of Prairie Creek. Zone C is a mixture of Zones D and B.

Important associations. An extensive fauna that includes many extinct and extralimital taxa is under study by Munson, Parmalee, Holman, Richards, and others.

Comments. Tomak (1975) identified *Martes* remains from the original Prairie Creek faunal sample but did not refer them to species. The fisher materials discussed above, and most of the fauna, are maintained at the Glen A. Black Laboratory of Archaeology, Bloomington, Indiana.

Published records. Richards, 1984, 1986, 1993; Tomak, 1975, 1982.

DISCUSSION

The fisher is now known to have inhabited Indiana during Late Pleistocene, mid to late Holocene, and historic times. Fisher bones have accumulated both in naturally formed as well as in culturally generated deposits. Moreover, its remains have been associated with those of now extinct mammals and with bones of such boreal forest species as *Phenacomys intermedius* (heather vole) and *Clethrionomys gapperi* (southern red-backed vole), which have not inhabited Indiana for thousands of years (Richards, 1986) as well as with remains of *Geomys bursarius* (Plains pocket gopher), which today inhabits relatively treeless areas (Mumford, 1969). Many Late Pleistocene faunas are composed of species that do not occur together today and that appear to be ecologically incompatible (Graham and Mead, 1987). The fisher appears more-often-than-not to have been a part of Indiana's fauna during the environmental change of Late Pleistocene and Holocene times, though it was scarcely noted in historic times. This is also the scenario in other States south of the fisher's present range. Fossils have been recovered from at least one Middle and ten Late Pleistocene localities in seven other states (Anderson, 1970): Arkansas: Conard Fissure, Newton County (Middle Pleistocene age; Brown, 1908); Peccary Cave, Newton County (*fide*; Kurten and Anderson, 1980); Georgia: Ladds Quarry, Bartow County (Ray, 1967); Missouri: Bat Cave, Pulaski County (Hawksley, *et al.*, 1973); Brynjulfson Cave I, Boone County (Parmalee and Oesch, 1972); Ohio: Carter, Darke County (Kurten and Anderson, 1980); Pennsylvania: New Paris No. 4, Bedford County (Guilday, *et al.*, 1964); Tennessee: Baker Bluff Cave, Sullivan County (Guilday, *et al.*, 1978); Robinson Cave, Overton County (Guilday, *et al.*, 1969); Virginia: Natural Chimneys, Augusta County (Guilday, 1962); Straight Canyon Fissure, Franklin County (Anderson, 1970, 1984).

The fisher has been recovered from at least 41 Holocene sites (primarily archaeological) in 14 other states: Alabama: Laws (Barkalow, 1961); Georgia: Etowah (Parmalee, 1960); Illinois (Purdue and Styles, 1986): Cahokia (Parmalee, 1958), Crawford Farm (Parmalee, 1960a, 1964), Laurens (Martin, 1984), Pabst (Lewis, 1979), Zimmerman (Rogers, 1975), and name unavailable, Cass County (Parmalee, 1960a); Iowa: Rock Run (Semken, 1983); Kentucky: Indian Knoll (Cleland, 1966; Webb, 1946); Michigan: Schuitz (Cleland, 1966); Minnesota: Bryan (Lunkens, 1963); Missouri: Arnold Research Cave (Parmalee, 1971), and Graham Cave (Parmalee, 1971); New York: Kipp Island (Cleland, 1966), Nahorld, Sylvan Lake (Anderson, 1970) and Wilson Sand Hill (Cleland, 1966); Ohio: Anderson, Baum, Cramer Village, Feurt, and Madisonville (Cleland, 1966); Pennsylvania: Eschelman (Cleland, 1966) and Meadowcroft (Guilday and Parmalee, 1982); Tennessee: Greenland, Watauga Cave (Anderson, 1970), and Westmoreland-Barber (Parmalee and Guilday, 1966); West Virginia: Buffalo (Anderson, 1970), Globe Hill (Guilday, 1956) and Johnston (Cleland, 1966); Wisconsin: Atztalan (Parmalee, 1960b), Bell (Parmalee, 1963), Bornick (Gibbon, 1971), Durst Rockshelter (Parmalee, 1960c), and Raddatz Rockshelter (Parmalee, 1959). Anderson (1970) lists several sites, though not by name.

In the eastern United States, the southern range of the fisher has retracted northward from Late Pleistocene glacial maxima through Late Holocene times to the historic period, after which it suffered a dramatic range reduction. Hall (1981) presents the historic (often 19th century) and Semken (1983) the present (for the eastern United States) distribution of the fisher.

Studies of Late Pleistocene and Holocene vertebrate faunas suggest that each species responds to climatic change according to its own "individualistic" physiological tolerances and ability to interface with varying suites of food, arrays of predators, types of habitat, and other taxa competing for a similar niche (Graham, 1984; King and Graham, 1981). During environmental change, animal ranges will adjust as individual units, rather than as totally shifting communities. The fisher has undergone a general northward restriction of its southern range, since the cool, wet climates of the Late Pleistocene glacial episodes. Perhaps in marginal habitat, the "individualistic" tolerances of the fisher were flexible enough for the maintenance of populations south of its historic distribution up to Late Holocene times, where the animal was occasionally taken by Native Americans. The fisher is not abundant in its current range (Powell, 1982) and during the historic period, already sparse populations were apparently reduced to critically low numbers of individuals. The pressure of the fur and logging industries during the late nineteenth and early twentieth century extirpated many populations in the United States and eastern Canada. Since then, there has been some recovery to former densities (deVos, 1964; Powell, 1982). The fisher was eliminated from Indiana's historic fauna by hunting, trapping, and reducing the habitat for what appears to have been an already critically low number of individuals at the tail end of a long-term, climatically-controlled restriction of its southern range.

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SKELETONS AND THE GENERA OF TANAGERS

J. Dan Webster
Hanover College
Hanover, Indiana 47243

ABSTRACT: There are 248 species of tanagers (Aves, Passeriformes, Thraupinae) arranged in 61 genera and known chiefly from their skins. The author studied 434 skeletons of 191 species of 57 genera, describing the shape or measuring 36 characters on each. Twenty-three characters proved useful in generic discrimination. Presence or absence of a free lacrimal; presence or absence of a manubrium-sternum bridge; shape and size of the interpalatine process; and the tibiotarsus/ulna length ratio were the best discriminants. The phylogeny of the tanagers remains unclear. More specimens must be studied.

INTRODUCTION

The 248 species of tanagers (Passeriformes, Emberizidae, Thraupinae) constitute a large, varied, colorful subfamily of neotropical birds. The last systematist to list all the known genera and species with their characters was Sclater (1886). Ridgway (1902) differentiated all the genera and those species found in North and Central American and the West Indies. Storer discussed the classification (1969) and listed all the forms (1970). Other important contributions were by Wetmore (1914), who described the peculiar stomach of *Euphonia*, and by Beecher (1951), who stated, mainly on the basis of jaw muscles, that several genera of honeycreepers belonged with the tanagers. Lucas (1894) and Bock (1985) differentiated genera of honeycreepers on the basis of tongue structure. Sibley (1970) studied the egg white proteins of 7 genera. Raikow (1978, 1985) devised a classification based mainly on the appendicular myology of 13 genera plus 4 borderline genera. Isler and Isler (1987) utilized the classification of Storer (1970), but their book is important because all the species of tangers are illustrated in color and the distribution, ecology, and behavior are summarized for each species. Sibley and Monroe (1990) listed all the species, classifying them on the basis of Sibley and Ahlquist's DNA work (1986, 1990) on 23 genera.

The classification of tanagers has been based on external anatomy, except for the partial work mentioned above on muscles, tongues, stomachs, and DNA. Skeleton studies have been reported by few workers. Shufeldt (1888) described two genera; Lucas (1894, 1895) mentioned 7 genera besides *Tersina*; Clark (1913) compared 3 genera; Beecher (1953) compared about 5 genera; Tordoff (1954) examined the skulls of 24 genera and figured 6; Berger (1957) examined the pneumatic fossa of the humerus in 15 genera; Bock (1962) of several (number not given) genera; Bock (1960) compared the palatine process of the premaxilla of 21 genera; George (1962) listed 19 genera besides *Tersina* in which he examined the hyoid; Cracraft (1968) mentioned that "most tanagers lacked a lacrimal" (genera unspecified); Lowery and Tallman (1976) in describing *Nephelornis* compared the skeleton with at least 5 genera of tanagers; Bock (1985) described the skulls of

TABLE 1. Genera of tanagers (following Storer, 1970) with the addition of a few species and genera (marked *) differentiated since that time and the subtraction of *Rhodinocichla* and 2 species of *Chlorospingus*.

Genera of Thraupinae	No. of species not examined	No. of species examined	No. of specimens examined
Orchesticus	1		
Schistochlamys		2	5
Neothraupis		1	1
Cypsnagra		1	3
Conothraupis	1	1	2
Lamprospiza		1	2
Cissopis		1	2
Chlorornis		1	4
Compsothraupis	1		
Sericossypha		1	2
Nesospingus		1	3
Chlorospingus	2	7	13
Cnemoscopus		1	2
Hemispingus	2	9	26
*Nephelornis**		1	5
Pyrrhocoma		1	2
Thlypopsis	2	4	9
Hemithraupis	1	2	9
Chrysothlypis	1	1	1
Nemosia	1	1	4
*Microligea**		1	10
*Xenoligea**		1	1
Phaenicophilus		2	5
Calyptophilus	1		
Mitrospingus	1	1	3
Chlorothraupis		3	6
Orthogonys		1	2
Eucometis		1	3
*Granatellus**		3	6
Lanio		4	6
Creurgops		2	2
Heterospingus		1	2
Tachyphonus		8	17
Trichothraupis		1	3
Habia	1	4	10
Piranga	1	8	33
Calochaetes		1	2
Ramphocelus	1	7	14
Spindali		1	2
Thraupis		8	20
Cyanicterus	1		
Buthraupis	5	4	8
Wetmorethraupis		1	2
Anisognathus	1	3	7
Stephanophorus		1	2
Iridosornis	1	4	5
Dubusia		1	2
Delothraupis		1	2

Genera of Thraupinae	No. of species not examined	No. of species examined	No. of specimens examined
Pipraeidea		1	2
Euphonia	7	18	33
Chlorophonia	2	2	6
Chlorochrysa	1	2	4
Tangara	10	38	64
Dacnis	5	4	9
Chlorophanes		1	4
Cyanerpes		4	11
Xenodacnis		1	3
Oreomanes		1	2
Diglossa	8	5	13
*Diglossopis**		3	7
Euneornis		1	6

Diglossa and *Diglossopis*; and Morony (1985) compared *Sericossypha* with 42 other genera. In this paper, the skeletons of all available species are compared.

MATERIALS AND METHODS

Through the courtesy of 14 museums, 434 tanager skeletons, representing 191 species of 57 of the 61 genera, were studied (see Table 1). In addition, numerous skeletons from a number of possibly related groups were studied (see page 590 for list). On each skeleton, 36 characters were measured with a dial caliper, or their shape was noted using a dissecting microscope. For most mensural characters, a ratio of measurements of 2 different skeletal elements is reported rather than the actual single measurement. All figures were drawn with the aid of a camera lucida. The ruled line is one millimeter in each case.

RESULTS

Twenty-two of the 36 characters proved somewhat useful in generic discrimination; they will be considered in order of clarity or usefulness. The first 7 characters, at least, may separate lines of evolution ("clades") of groups of genera. However, this suggestion is quite tentative. Too few skeletons (none of 4 genera; none of 57 species) were available; several species appeared to have been placed in the wrong genus; perhaps the wrong anatomical features were studied.

(1) The lacrimal was present as a distinct free bone, anterior to the ectethmoid plate, in all specimens of 13 genera (*Schistochlamys, Neothraupis, Cissopis, Chlorornis, Cnemoscopus, Pyrrhocoma, Calochaetes, Anisognathus, Stephanophorus, Iridosornis, Dubusia, Delothraupis,* and *Diglossa*) and in some specimens or species of 12 genera. In all specimens of the other 32 genera, it was either missing or fused with the ectethmoid plate. Usually it was impossible to say whether the lacrimal was missing or fused, but in a few cases, there was an evident suture,

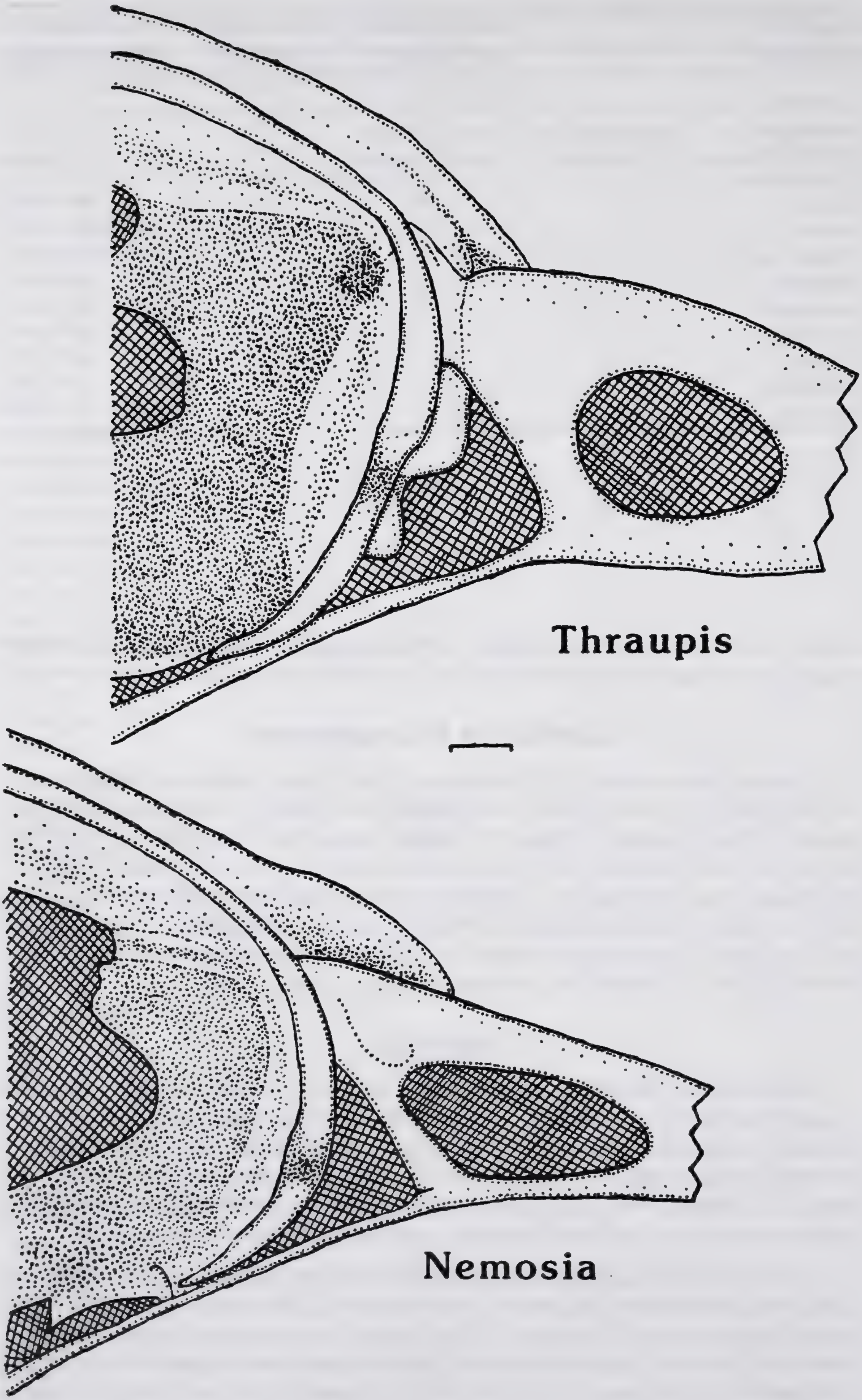

FIGURE 1. Lateral views of skulls of *Thraupis sayaca* and *Nemosia pileata*, drawn to the same scale. There is a free lacrimal in *Thraupis*.

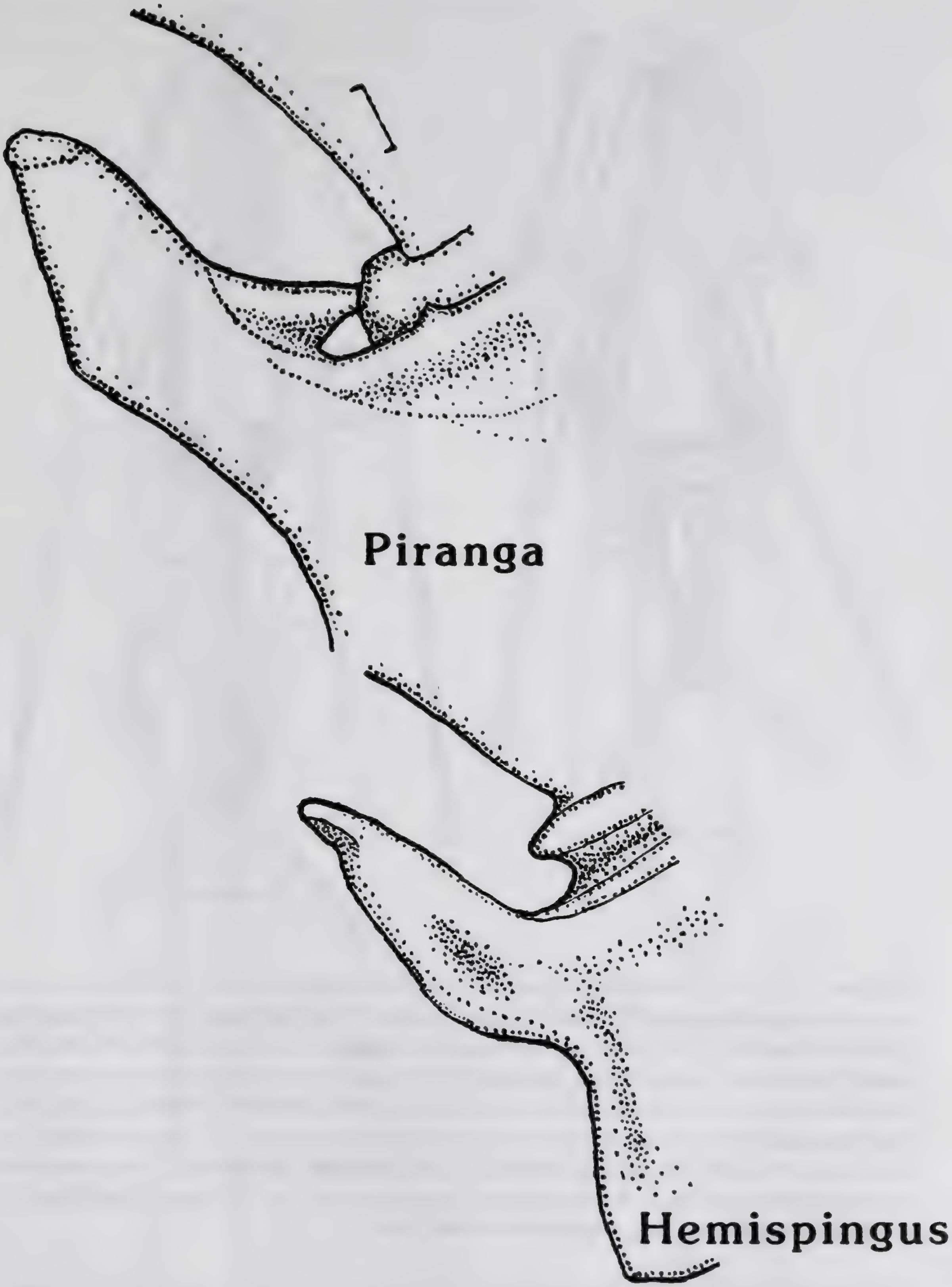

FIGURE 2. Lateral views of anterior part of sternum of *Piranga bidentata* and *Hemispingus superciliaris*, drawn to the same scale. There is a large manubrium-sternum bridge in *Piranga*.

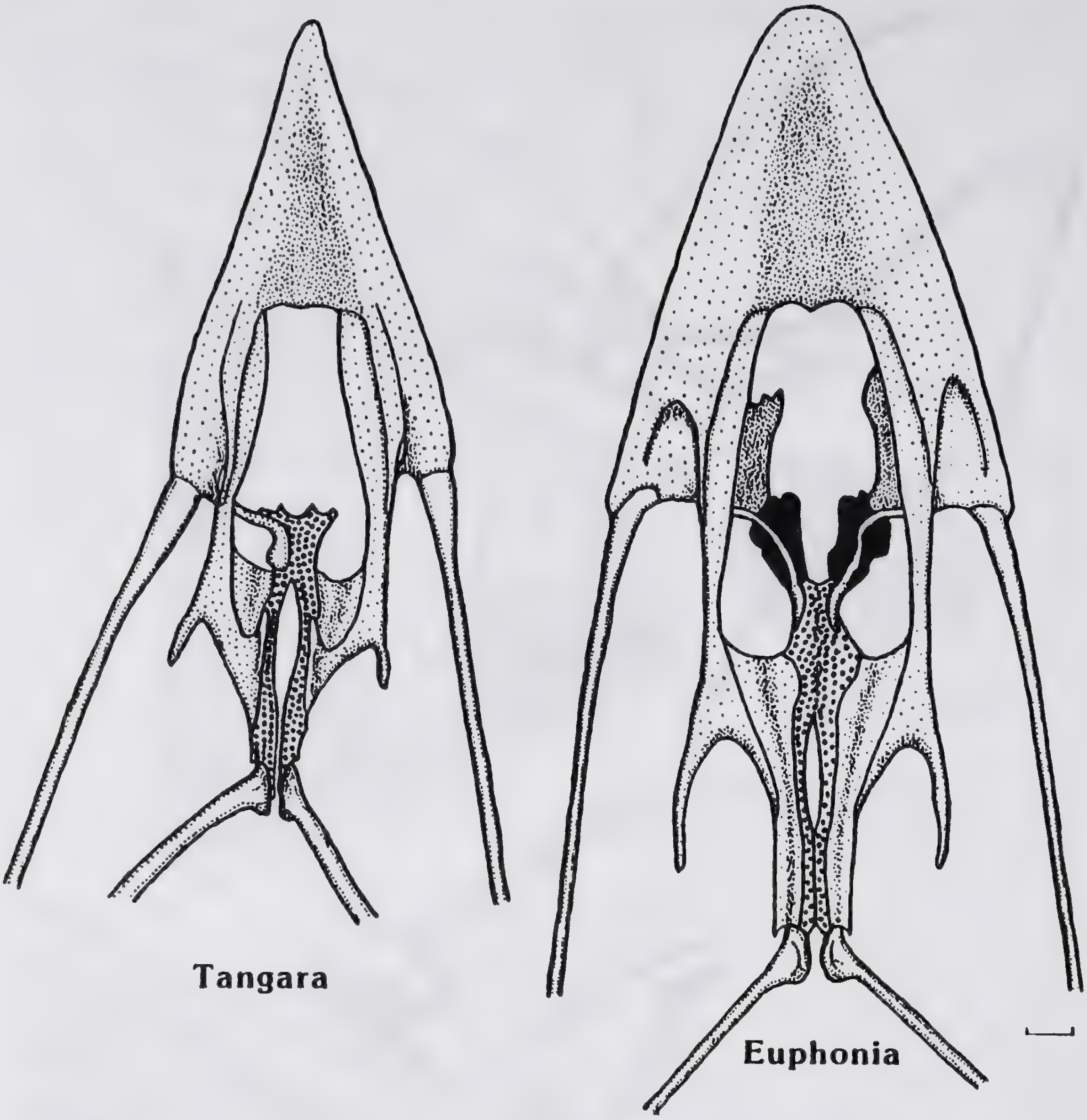

FIGURE 3. Ventral views of palates of *Euphonia chalybea* and *Tangara punctata*, drawn to the same scale, vomers coarsely stippled. In *Euphonia*, the interpalatine process is lacking; the palatine process of the premaxilla is small but evident; the lateral margin of the palatine posteriorly is concave; the transpalatine process is 4 times as long as wide; and the bony nasal capsules are drawn black. In *Tangara*, the interpalatine process is moderate; the palatine process of the premaxilla is small but evident; the lateral margin of the palatine posteriorly is concave; the transpalatine process is 6 times as as long as wide; the left maxillopalatine is broken off; and the nasal capsules are not bony.

indicating fusion. When present, the bone was nearly always pneumatic; in some species, it was larger than the one drawn (Figure 1, upper drawing) and in others smaller.

(2) The interpalatine process of the palatine was very small or missing entirely in all specimens of 7 genera (*Chlorornis, Calochaetes, Buthraupis, Iridosornis, Dubusia, Pipraeidia,* and *Cyanerpes*) and in some species or specimens of 14 more, but it was always long or of moderate size in 36 genera (Figure 2).

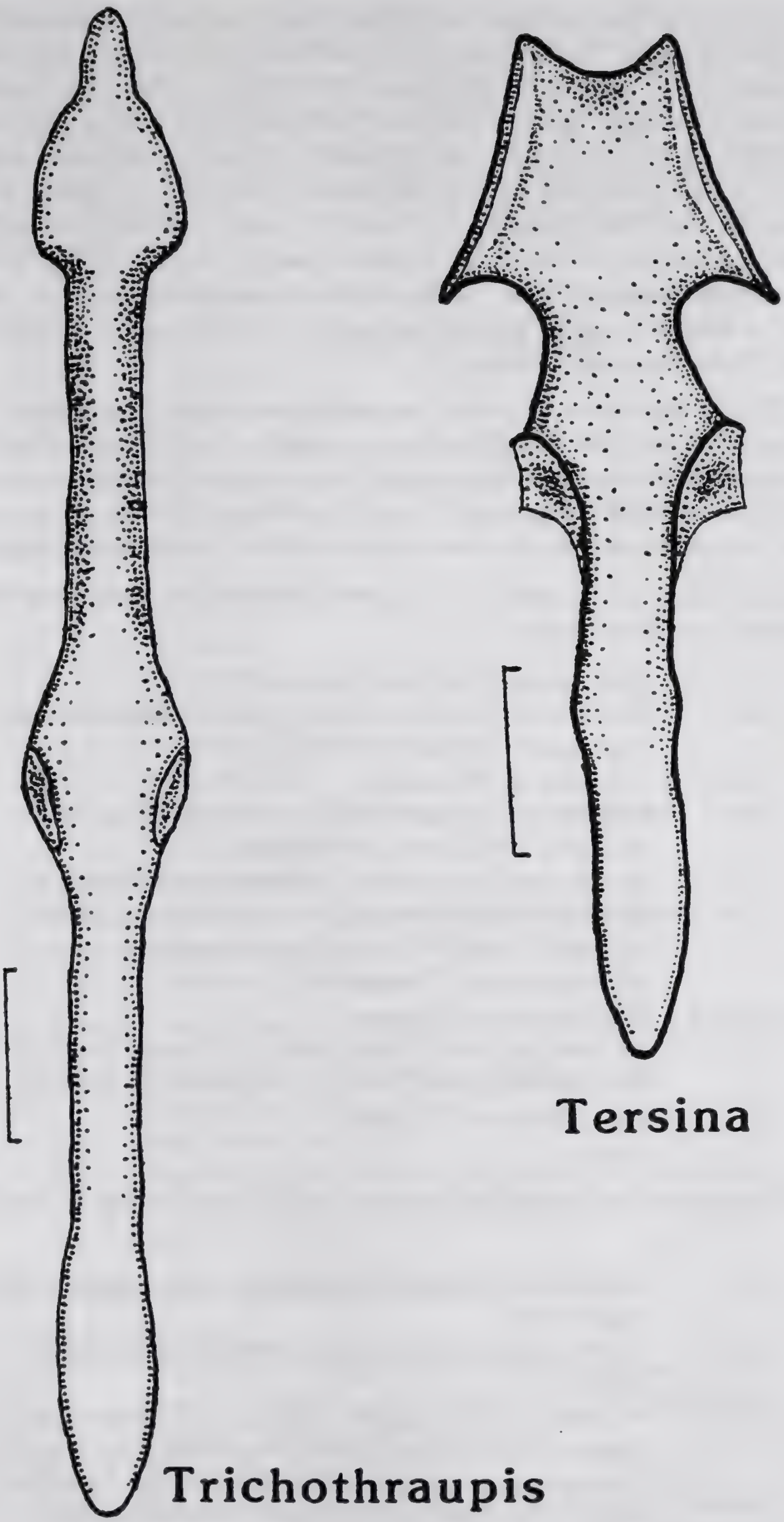

FIGURE 4. Ventral views of basihyoid and basibranchial of *Trichothraupis melanops* and *Tersina viridis*.

(3) The manubrium-sternum bridge was always present in 5 genera (*Conothraupis, Heterospingus, Habia, Cyanerpes,* and *Chlorophanes*) and was present in some specimens of 7 genera (*Sericossypha, Hemithraupis, Nemosia, Nephelornis, Tachyphonus, Piranga,* and *Xenodacnis*); in these 12 genera, it was always or usually large. In 15 more genera, the manubrium-sternum bridge was sometimes present as a very small structure; in 30 genera, it was always absent (Figure 3). The structure was first described by Shufeldt (1888) and emphasized by Clark (1913). It is neither universal in the tanagers, as suggested by Clark, nor unique to *Sericossypha* (*contra* Morony, 1985). As noted elsewhere (Webster, 1993), the structure is largest in some finches and cardinals of the genera *Rhodothraupis, Fringilla, Bubalornis,* and *Dinemellia.*

(4) The palatine process of the premaxilla was large or moderate (Tordoff, 1954, classes P1 and P2) in all specimens examined of 7 genera (*Neothraupis, Conothraupis, Chlorothraupis, Creurgops, Heterospingus, Piranga,* and *Euneornis*) and some specimens of 16 genera. It was small but evident in all specimens of the other 34 genera, except for a very few in which it was absent (Figure 2).

(5) Calculation of the mean of the ratio of tibiotarsus length/ulna length for each species gave these figures:

2.1 - *Hemispingus rufosuperciliosus.*
1.9 - *Nephelornis* and *Xenodacnis*; 1 species of *Habia*; and 1 species of *Diglossa.*
1.8 - 1 species of *Thlypopsis.*
1.7 - *Dubusia* and 1 species each of *Chlorospingus, Hemispingus, Thlypopsis,* and *Diglossa.*
1.6 - *Pyrrhocoma, Microligea, Xenoliga,* and *Delothraupis;* 3 species of *Hemispingus;* 2 species each of *Chlorospingus* and *Diglossa;* and 1 species each of *Iridosornis* and *Thlypopsis.*
1.5-1.2 - Most species and genera.
1.1 - *Sericossypha* and *Wetmorethraupis*; 3 species each of *Tachyphonus* and *Thraupis*; 2 species of *Piranga*; and 1 species of *Tangara.*
1.0-.9 - *Lanio.*

(6) The mean of the ratio of tibiotarsus length/femur length for each species was:

2.0 - *Xenodacnis*; 2 species of *Diglossa*; and 1 species of *Diglossopis.*
1.9 - 2 species each of *Diglossa* and *Hemispingus*; and *Diglossopis.*
1.9 - *Pyrrhocoma, Thlypopsis, Nephelornis, Microligea, Granatellus, Spindalis,* and *Oreomanes*; 4 species of *Hemispingus*; 2 species of *Iridosornis*; and 1 species each of *Chlorospingus, Diglossa,* and *Diglossopis.*
1.7-1.5 - Most species and genera.

(7) The ectethmoid foramen was always single in 18 genera (*Neothraupis, Conothraupis, Lamprospiza, Cissopis, Chlorornis, Nesospingus, Chlorothraupis, Eucometis, Granatellus, Trichothraupis, Habia, Piranga, Orthogonys, Stephenophorus, Dubusia, Delothraupis, Pipraeidea,* and *Oreomanes*) and always double in 6 (*Sericossypha, Phaenicophilus, Xenoligea, Mitrospingus, Heterospingus,* and *Euneornis*). It was mixed (either single, double and pinched; or single and pinched; or double and pinched; or double and single; or always pinched) in various specimens of 33 genera.

(8) The ratio of braincase width/supraorbital width for each species was:

7.0-6.3 - *Cypsnagra* and 3 species of *Thlypopsis.*
6.1 - *Nephelornis.*
5.9-3.1 - Most species and genera.
3.0-2.6 - *Cissopis* and *Sericossypha*; 2 species of *Chlorothraupis*; 3 species of *Piranga*; 2 species each of *Rhamphocelus* and *Lanio*; and 1 species of *Thraupis.*
2.1 - 1 species of *Piranga.*

(9) Premaxillary length/width was:

3.7-2.9 - *Cyanerpes.*
3.4 - *Oreomanes.*
3.1-2.2 - *Diglossa.*
2.7-2.6 - 2 species of *Diglossopis.*
2.5-2.2 - *Phaenicophilus.*
2.2-2.1 - *Sericossypha, Microligea,* and *Chlorophanes*; 2 species of *Thlypopsis.*
2.0-1.3 - Most species and genera.
1.2-1.1 - *Stephanophorus*; 3 species of *Tangara*; 2 species of *Anisognathus*; and 1 species of *Thraupis.*
1.2-0.9 - 12 species of *Euphonia.*

(10) Skull length was the only absolute size (mm) measure used. It was:

31-29 – *Sericossypha* and 3 species of *Buthraupis.*
28 - *Cissophis* and *Chlorornis.*
27-18 - Most species and genera.
17-16 - *Chrysothlypis*; 4 species of *Euphonia*; and 1 species each of *Tangara, Dacnis, Hemithraupis,* and *Diglossa.*

(11) Tarsometatarsus length/femur length was:

1.6-1.4 - *Diglossa*
1.4 – *Pyrrhocoma, Nephelornis, Microligea,* and *Oreomanes*; 2 species each of *Diglossopis* and *Hemispingus*; and 1 species of *Thlypopsis.*
1.3-1.1 - Most species and genera.
1.0 - *Calochaetes, Wetmorethraupis;* 5 species of *Thraupis*; 4 species each of *Piranga* and *Tangara*; 3 species each of *Euphonia* and *Lanio*; 2 species of *Rhamphocelus*; and 1 species of *Chlorophonia.*
0.9 - *Sericossypha.*

(12-23) Ratio of tarsometatarsus length/width separated 10 genera and parts of 14 genera from the rest. Length of the transpalatine process separated 13 genera and parts of 13 more from the rest. Length of the retroarticular process of the mandible separated 1 genus (*Oreomanes*) and parts of 3 others from the rest. Shape of the orbital process of the quadrate separated 1 genus (*Oreomanes*) and parts of 13 genera from the rest. Length of the pseudotemporal process of the mandible separated 10 genera and parts of 12 others from the rest. Shape of the lateral margin of the palatine posteriorly separated 1 genus (*Neothraupis*) and parts of 20 more from the rest. Ratio of tibiotarsus length/humerus length separated 11 genera and parts of 10 from the rest. Ratio of tibiotarsus length/ tarsometatarsus length separated 8 genera and parts of 11 from the rest. Shape of the squamosal (= suprameatic) process separated 4 genera and parts of 8 genera from the rest. Ratio of ulna length/humerus length separated 2 genera and parts of 7 others from the rest. Shape of the pneumatic fossa of the humerus separated one genus (*Sericossypha*) from the rest. Shape of the maxillopalatine separated 20 genera from the rest.

(24-36) These characters were observed or measured on each specimen but were much too uniform for generic discriminants: fronto-nasal hinge mobility, basihyoid-basibranchial shape, angle of internal tuberosity of humerus with shaft, ratio of ulna length/femur length, ratio of humerus length/femur length, shape of the internal process of the mandible, relative digit (= trochlear) lengths of metatarsus, and distal bend of tarsometatarsus. These characters were observed but were too variable within each species or each genus to be generic discriminants: shape of ectethmoid plate margin, internasal septum and nasal capsules (apparently defective specimens were too common, but bony nasal capsules were usually present—present in all or most specimens in 16 of the 18 species—in *Euphonia*, as shown in Figure 3, and only 5 other genera; more and better specimens will probably demonstrate this to be a valid generic character), shape of lateral process of nasal, shape of anterior end of vomer, and process 7b of mandible. Also, 11 more characters, mostly of the vertebrae and ribs, were rcorded on most of 59 specimens of 48 species of tanagers in earlier years in connection with my studies of warbler skeletons (Webster and Goff, 1979; Webster, in prep.). None provided useful information for generic classification.

In the pages above, neither the question of the boundary of the subfamily Thraupinae nor its relationship to other groups was addressed; the author has instead, simply considered the genera and species as listed by Storer (1970), added the new species and two genera described since, plus 3 genera the author had transferred from Parulinae in an earlier paper (Webster, in prep.). Also, the author removed one genus (*Rhodinocichla*) to Parulinae, following Ridgway (1902) but *contra* Storer (1970). The skeletons of *Rhodinocichla* and other borderline or recently questioned genera (*Conirostrum, Coereba, Tersina, Catamblyrhynchus, Rhodospingus, Coryphospingus,* and *Paroaria*) were compared as well as 24 (all but one) of the genera of Parulinae, 49 of the genera of Emberizinae, 19 of Icterinae, and 7 of Cardinalinae. The 7 skeletons of *Rhodinochinhla rosea* examined fit better with the warblers (Parulinae) than with the tanagers (Thraupinae) on each of the subfamily characters mentioned below.

In the DNA classification of Sibley and Ahlquist (1986, 1990), the tribe Thraupini includes the tanagers, all of the borderline genera mentioned above, and many of the genera usually (Paynter, 1970) assigned to Emberizinae. Especially at the level of tribes and genera, it is unwise to base a new classification on only one type of evidence, when the authors have examined only 38% of the genera of tanagers and 32% of the genera of emberizines. Raikow's (1978, 1985) classification is based on evidence from even fewer genera. The average linkage clustering tree showing DNA relationships within the tanagers as presented by Sibley and Ahlquist (1990, p. 870) was compared closely with this skeletal data, as were their various melting curves and their Fitch tree. Correlation was virtually absent with the 11 skeletal characters which ranked highest for generic distinctions (above). Correlation of Sibley and Ahlquist's data with the classification of Storer (1970), based principally on plumage and other external anatomy, was also very poor.

The unique anatomy of the swallow tanager (*Tersina viridis*) is worth emphasis. Figure 4, right drawing, shows the basihyoid + basibranchial in contrast with that of a typical tanager. In *Tersina*, not only is the basihyoid short and stout; it is round in cross-section medially, and the anterior end is almost T-shaped rather than sagittate. The shape of the basihyoid as shown in *Trichothraupis* (left drawing) is similar to that in all other 9-primaried new world oscines except for *Tersina* and *Peucedramus* (George, 1962; Webster, in prep.). *Peucedramus*, the olive warbler, has a hyoid which is less aberrant than that of *Tersina*, for the anterior end is almost normal, and only the median part is peculiar—round in cross-section rather than compressed. In *Tersina*, the entire posterior palatine shelf is missing, including the transpalatine process (Lucas, 1895; Tordoff, 1954). The ratio of braincase width/supraorbital width (2.4) is less than in all but one species of tanager. The pseudotemporal process of the mandible is smaller than in any tanager—indeed missing entirely in 2 specimens. The tibiotarsus/tarsometatarsus ratio is higher than in any tanager. In other features studied, *Tersina* fitted within the variation found in tanagers.

A definition of the subfamily Thraupinae (genera as listed in Table 1) on the basis of mostly skeletal characters is: insectivorous, nectarivorous, or frugivorous (or a combination of those) 9-primaried new world oscines; skeleton lightly or moderately built; premaxilla (or bill) moderately stout or slender; maxillopalatine club pneumatic and usually fat; palatine process of the premaxillary evident and sometimes prominent; lateral margin of palatine posteriorly almost always straight or concave; transpalatine process slender, usually more than 3 times as long as wide; orbital process of quadrate nearly always longer than rest of quadrate and usually with little taper; basihyoid compressed medially and sagittate anteriorly; pneumatic fossa of humerus usually of combined type, although often with a slight medial bar or step-down, or rarely double with a prominent medial bar; and internal tuberosity of head of humerus making an angle of 55-70° with shaft, usually 60° or more.

DISCUSSION

Any good classification is based on a wide variety of data. Therefore, the skeletal features described here are inadequate for a rigorous systematic revision of the tanagers. However, new data presented here may help to resolve some problems. Several species may have been placed in the wrong genera in *Hemithraupis, Hemispingus, Thraupis, Buthraupis, and Tangara,* because these genera show such great variability in the skeleton. On the other hand, almost no skeletal differences were found between *Euphonia* and *Chlorophonia,* between *Delothraupis* and *Dubusia,* and between *Tachyphonus* and *Trichothraupis*. Perhaps, these pairs of genera, in each case already placed side-by-side by Storer (1970), should be united. The very distinct skeletal features of *Tersina* confirm the traditional placement of that species in a separate subfamily or family.

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BAT COLONIES IN INDIANA, WITH EMPHASIS ON THE EVENING BAT, *NYCTICEIUS HUMERALIS*

John O. Whitaker, Jr. and Sherry L. Gummer
Indiana State University
Terre Haute, Indiana 47809

The evening bat, *Nycticeius humeralis*, is currently on the endangered species list of Indiana. The first individual of this species from Indiana was taken by C.H. Conaway in Dearborn County in 1942 (Kirkpatrick, 1943). Kirkpatrick and Conaway (1948) reported an additional specimen taken in 1947 in Tippecanoe County. Mumford (1953) recorded an additional eight individuals, five from Tippecanoe County and three from Clay County, two of the latter as they emerged from a house in Brazil and a third from a different location in the same city. Lindsay (1956) shot another eight individuals near farm ponds near Rexville in Ripley County, three of whom had embryos. Records of bats of this species from 29 counties were reported by Mumford and Whitaker (1982), but there are substantially fewer records in recent years (Whitaker and Gammon, 1988).

Cope, *et. al.* (1961) initiated an extensive study to locate bat colonies in Indiana. They advertised in newspapers and elsewhere for leads and located 188 colonies: 142 of the big brown bat, *Eptesicus fuscus*, 41 of the little brown bat, *Myotis lucifugus*, 1 of the pipistrelle, *Pipistrellus subflavus*, and 4 active colonies of the evening bat, *Nycticeius humeralis*. The four colonies of the evening bat were in Clark, Clay, Orange, and Washington Counties, respectively, with an estimated total of 460 bats. Including these colonies, Mumford and Whitaker (1982) reported maternity colonies from 10 counties: Carroll, Cass, Clark, Clay, Clinton, Montgomery, Orange, Tippecanoe, Washington, and White. All of the colonies were from attics in houses. Six of these were known to be active in the early 1960's, but all were apparently inactive as of 1985.

The main purpose of the present study was to locate maternity colonies of the evening bat for study of habitat requirements, food habits, ectoparasites, reproduction, and other aspects of the ecology of this species. Such data should help us determine means of helping them survive as a component of the fauna of Indiana. A secondary purpose was to locate maternity colonies of all species of bats in buildings for comparison with the data collected by Cope, *et. al.* (1961).

MATERIALS AND METHODS

To locate colonies, over 2000 "Bats Wanted" posters were distributed, and publicity appeared in several papers and on television. These efforts produced 499 leads, nearly all of which were explored as of 1 November 1988.

This study was originally centered in west-central Indiana, but it was soon expanded to cover the entire State. As leads were obtained, they were given consecutive numbers and entered on keysort cards. Additional data (type of building and roof, mode of entry, locations of bats, etc.) were entered on the cards, when the sites were visited.

DISCUSSION

A total of 231 maternity colonies of four species of bats was found:

Evening bat, *Nycticeius humeralis*	1
Eastern pipistrelle, *Pipistrellus subflavus*	7
Little brown myotis, *Myotis lucifugus*	34
Big brown bat, *Eptesicus fuscus*	189

The most important objective was partially fulfilled as one maternity colony of the evening bat was found. It is in Briley Chapel, a church about five miles west of Clay City, Clay County, Indiana. The colony is in a very protected area at the top of the bell tower. The only access for humans to where the bats occur is through a 65 x 65 mm opening through the ceiling over the bell. This opening is covered by a 260 x 260 mm section of plywood nailed to the ceiling. Since over 20 cm of guano covered the opening, the authors assumed it had not been opened in several years. Two bats were collected from the colony for identification and were preserved as voucher speciments.

At dusk on 27 July 1987, 358 bats were counted exiting from the colony. In 1988, there were still 31 bats present on 16 October, although all had left a week later. Fortunately, church personnel have been inclined to help protect the bats and to assist in our studies. The colony is being studied further.

Relatively few eastern pipistrelle colonies have been found. Most have been in buildings and other man-made structures, but two were in caves in Missouri (Humphrey, *et al.*, 1976). It is likely that they also use hollow trees. Six small colonies of pipistrelles were located during these studies. Numbers of females per colony were 2, 10, 11, 11, 13, and 13. Most could be reached by standing on the ground or from a short stepladder. Most were in relatively new rather than old buildings. One was on the outside of a house in full sunlight, two were in small sheds, two were in garages, and one was in a pavillion. One colony apparently moved, because in 1986, one of the colonies was found in a small shed. It was composed of 11 adult females. The shed was converted to a chicken house, and in 1988, four females were found in the nearby garage. All colonies contained babies, and all had been vacated by early August.

Ten of the 34 little brown bat colonies were in houses, 8 were in barns, 7 were in churches, 5 were in stores, and 1 each were on a porch, in a trailer breezeway, in a garage, and in expansion joints under a bridge.

One of the little brown bat colonies is particularly interesting because of its size. It is in a barn south of Brazil in Clay County. The authors counted over 6,700 bats emerging from this barn in August 1987 and feel that that count may underrepresent actual size. This could be the largest extant maternity colony of this species. There was a colony of 9,640 "bats" in a brick building in Maryland with about 2,000 bats in an adjacent building (Morano, 1864). The species was not indicated, but the authors suspect that those bats were *Myotis lucifugus*. The colony at Brazil is presently being protected. The barn is owned by a church, and church personnel are sympathetic both to preserving the bats and to the long-term banding and other studies that the authors have initiated.

The second largest colony found was in a church and contained about 4,000 bats. The third largest was in the expansion joints under a bridge near Hymera in Sullivan County. That colony probably contains at least 3,600 bats. Other than in the colonies indicated above, the estimates (probably low) of numbers in 27 little brown bat maternity colonies ranged from 20+ to 1,640 ($\bar{x}$ = 449, SE = 91.5). Including the two large colonies, the mean colony size was 752.8 (SE = 245.1).

A total of 189 colonies of the big brown bat was located, the largest being 560 adults in a house in Needham, Johnson County, Indiana. Colonies were located as follows: 62 in barns, 43 in churches, 40 in houses, 20 in stores, factories, and the like, 10 in schools, 8 in garages, sheds, and cabins, and 6 in miscellaneous locations.

Little is known of the winter habits of big brown bats. They hibernate in caves and mines, but not nearly enough winter in these situations to account for the large numbers in maternity colonies. Also, big brown bats continually appear in winter in buildings not in cave areas. Barbour and Davis (1969) state, "We need to learn more of the whereabouts of these bats (*Eptesicus*) in winter. It is reasonable to suppose that in regions with cold winters most of them hibernate in buildings where they are not often encountered." We have hypothesized that some of these spots may be in the summer quarters, if warm enough, but many of them are likely to be in nearby buildings. To test this hypothesis, the authors revisited in winter 24 buildings containing summer colonies that would appear to serve as possible hibernacula in winter and found 2 to 72 big brown bats hibernating in 10 of these. The authors also examined the attics of houses where big brown bats were found downstairs in the winter of 1987-88. There were 14 such cases, and the authors found from 1 to 7 bats hibernating in each of 7 locations.

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